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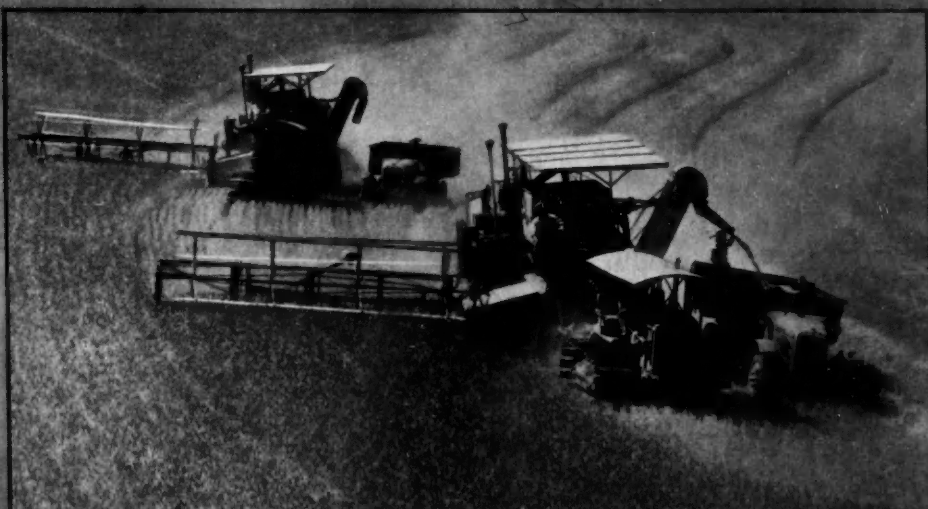

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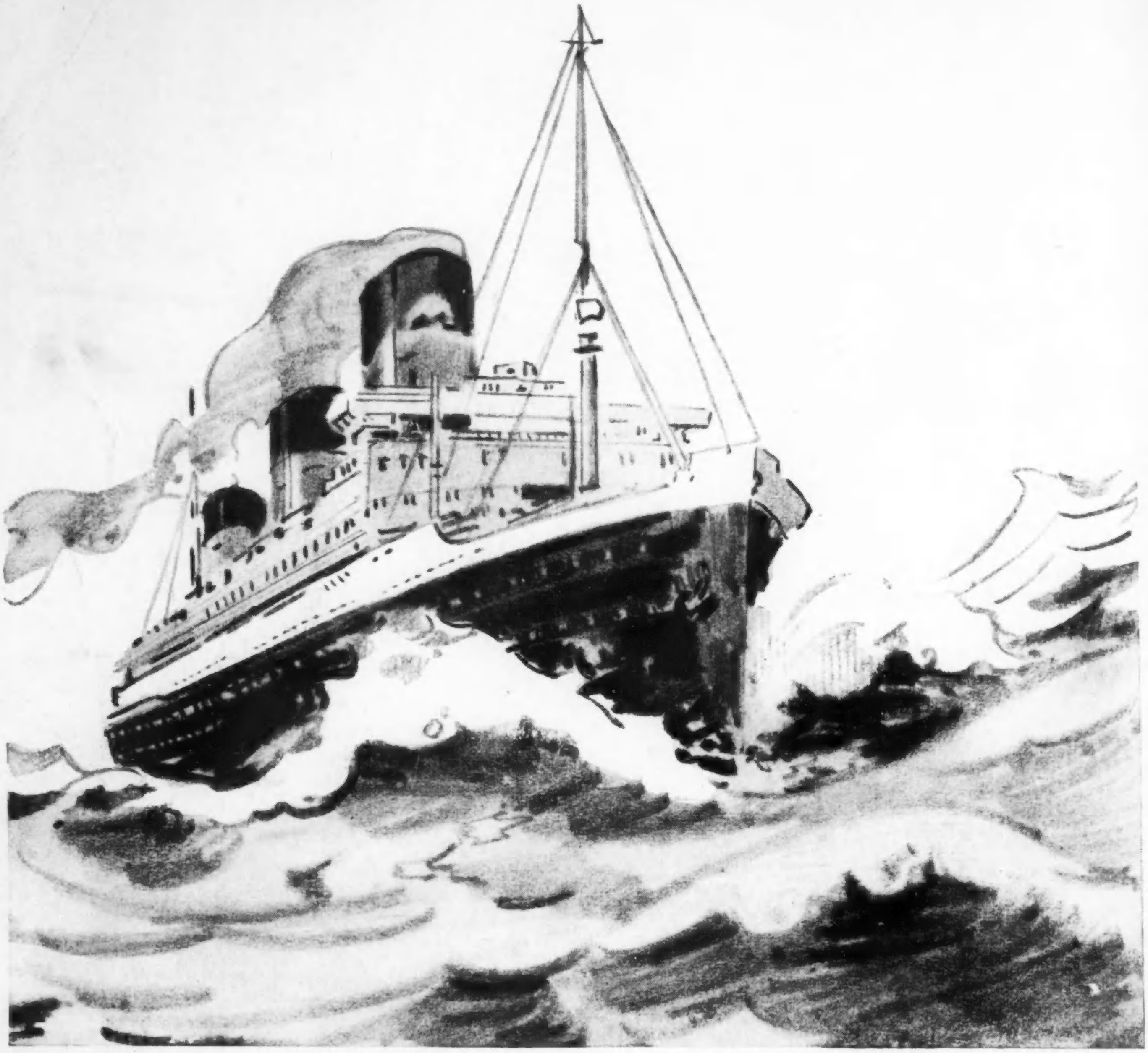

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VOL. XXIX, No 3 September, 1931

S.A.E. JOURNAL

Published by the Society of Automotive Engineers, Inc.

October National Production Meeting

Plans Maturing for Two Days Devoted to Five Papers on Important Subjects, a Plant Visit and a Dinner

TECHNICAL sessions of the 10th National Production Meeting of the Society will be held in the Crystal Room of the Book-Cadillac Hotel in Detroit, Oct. 7 and 8.

The Production Activity Committee planned the meeting to be of such value as to make it desirable from the management point of view that production engineers and supervisors attend. By doing so they can not only get directly the meat of the papers and the discussion of them, but can add materially to the general value of the meeting by contributing their own ideas and experience on the subjects discussed.

Preprints of all the papers are expected to be available at the New York City office of the Society prior to the meeting, to afford opportunity for preparing written discussion of each topic. Engineers who are unable to attend the meeting but desire to contribute to the discussion of papers are invited to send their remarks to the Society so they can be presented at the sessions by the Chairmen.

The program of the meeting, as definitely arranged at the time this issue of THE JOURNAL was closed for the press, is printed on p. 177.

Subjects Dealt with in Papers

The session on the first morning will be devoted entirely to discussion of welding, which is a process that takes first rank in importance, especially in body building. The author of this paper is a man of probably as wide experience and skill in this method of manufacturing as anyone in the industry.

The afternoon session will be devoted to two important papers. The first, dealing with the control of inventory of manufacturing stocks and materials in process, concerns an economic factor in production that has become highly developed in the modern complex systems of factory organization and management. The topic is of particular concern to companies operating on the mass-production basis and is a factor that will probably be developed even further.

The second paper of this afternoon session will bring out many advanced ideas for practical improvements in the preparation of sheet-metal surfaces for the application of finishes. The introduction of nitrocellulose finishes, and in many instances the use of baked enamels on large surfaces such as fenders, have brought with them troubles that have not yet been entirely remedied.

Two papers relating to subjects that are allied, in that they treat of methods that are comparatively new in producing semi-finished parts, are scheduled for the morning of the second day. They will bear on the improvement in their respective methods of securing more accurate parts and will indicate the possibilities for savings in raw metal, machining, machine-tool equipment, labor and so forth. This session should be of particular importance in bringing them forward for general discussion.

Plant Visit and Production Dinner

The Detroit Section of the Society has arranged for a plant visit to the Holley Carburetor Co. on the afternoon of the second day and those attending the Production Meeting will be repaid for devoting their afternoon to this trip. The Detroit Section is a past master at arranging such visits and in getting members there and back in time for the closing event of the meeting—the Production Dinner.

The Production Dinner, which will meet the present economic needs so far as cost is concerned, is to be given in the grand ballroom of the Book-Cadillac and will be productive both of pleasure and of information. A. K. Brumbaugh—"Brummy" to those who know him well—will be toastmaster. "Brummy" is also the Society's Vice-President representing Production Engineering and Chairman of the Production Activity Committee. He will introduce a well-known speaker, who will speak on matters of real appeal to men and women, but not on production.

Following the foregoing address, there will be a live demonstration of The Electron at Work and at Play.

"Pop" Kreusser, Chairman of the Detroit Section, and his army of Section members are taking a keen interest in this meeting. Dinner tickets should be secured in advance from the Detroit Section office, room 2-136 General Motors Building, Detroit, or through the New York City office of the Society.

S.A.E. Session at Metal Congress

Three Excellent Metallurgical Papers To Be Presented in Boston on Sept. 23

THIS YEAR the Society is cooperating with other engineering societies by having a technical session at the National Metal Congress to be held in Boston in connection with an exhibition during the week Sept. 21 to 25. The other National organizations that will participate in the Congress are the American Society for Steel Treating, the American Welding Society, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers.

The S.A.E. will hold its technical session in the Georgian Room of the Hotel Statler on Wednesday morning, Sept. 23, at 9:30 o'clock. F. P. Gilligan, Chairman of the Iron and Steel Division of the S.A.E. Standards Committee, will preside. He has been active for many years in the Society's work, is a past-president of the American Society for Steel Treating and is a leading authority of wide experience in metallurgical engineering.

Subjects Treated in the Papers

The program of the session comprises three timely papers on important subjects, two of which deal with the methods and costs of heat-treating and make available valuable information bearing more on the economics of the subject than on its purely metallurgical phases. One of these two S.A.E. papers is to be presented by E. F. Davis, the metallurgist of the Warner Gear Co., and the other by Dr. Haakon Styri, of S. K. F. Industries, Inc.

The third paper at the S.A.E. Session, which is to be read by F. W. Shipley, foundry metallurgist of the Caterpillar Tractor Co., is devoted to the metallurgical characteristics and advantages of alloyed cast irons, particularly for use in cylinder castings.

The number of papers to be given at this session has been limited by the Society so that each can be presented in full and ample time allowed for general discussion. Preprints of the papers are expected to be available prior to the week of the Congress, at the offices of the Society, 29 West 39th Street, New York City.

Papers at Sessions of Other Societies

At the technical sessions of the other National organizations cooperating in the Metal Congress, a number of papers will be presented that are of more or less direct interest to the automotive industry. A number of those to be given at sessions of the American Society for Steel Treating are: Cemented Tantalum Carbide; and Resistance to Wear of Carbon Steels and Tool Steel from the Consumers' Standpoint, on Monday morning; The Evaluation of the Drawing Quality of Extra-Deep Drawing Sheets; Effect of Normalizing upon the Grain Structure and Physical Properties of Automobile Sheet Steel; and Plastic Drawing of Sheet Steel into Shapes, on Tuesday morning; Identification of Inclusions; Ghost Lines in Forgings; and Scaling of Steel at Elevated Temperatures by Reaction with Gases and the Properties of the Resulting Oxides, on Tuesday afternoon. Stainless Alloys, on Friday morning, and Nitriding, on Friday afternoon, will also be sessions of interest to members of the S.A.E.

Metal Exposition and Plant Visits

The National Metal Exposition, which will cover 60,000 sq. ft. of floor space, will be on Commonwealth Pier, Boston, Sept. 21 to 25 inclusive, and will consist of exhibits and demonstrations arranged by nearly 200 companies.

Several interesting and instructive plant visits for those attending the Congress have been arranged for, among which are trips to the Watertown Arsenal on Tuesday morning and to the East Lynn Works of the General Electric Co. on Thursday morning. Arrangements are in progress or have been completed for a number of other plant visits during the week.

CALENDAR

National Meetings

20th National Aeronautic Meeting—Sept. 1 to 3
Hotel Statler, Cleveland
In conjunction with the National Air Races

National Metal Congress—S.A.E. Session—Sept. 23
Hotel Statler, Boston
In cooperation with American Society for Steel Treating, American Welding Society, American Institute of Mining and Metallurgical Engineers and American Society of Mechanical Engineers

10th National Production Meeting—Oct. 7 and 8
Book-Cadillac Hotel, Detroit

9th National Transportation Meeting—Oct. 27 to 29
Shoreham Hotel, City of Washington

September Section Meetings

Cleveland—Sept. 10
Big Ten Alumni Club; Golf Tournament 3:00 P. M.; Dinner

Indiana—Sept. 24
Hotel Severin, Indianapolis; Dinner 6:30 P. M.; Meeting 8:00 P. M.
Review of Air Races and Gold Cup Race, with Special Reference to Developments in the Industries

Metropolitan—Sept. 24
A.W.A. Clubhouse, 353 West 57th Street, New York City; Dinner at 6:30 P.M. Aeronautic Meeting

New England—Sept. 9
Hotel Kenmore, Boston; Dinner 6:30 P. M.; Meeting 8:00 P. M.
Relations of the Commonwealth to Truck and Bus Operators—Morgan T. Ryan, Registrar of Motor-Vehicles
Service-Station Equipment for Safety Drives

Northwest—Sept. 11 and 12
Seattle, Wash., Sept. 11
Electric Nitriding Furnaces—H. M. Gustafson, General Electric Co.
Vancouver, B. C., Sept. 12
Flame—Prof. F. G. Baender, Oregon State College

Oregon—Sept. 4
Multnomah Hotel, Portland; Dinner 6:30 P. M.; Entertainment; Motion Pictures
Speakers: H. W. Roberts, Roberts Motor Truck Co., and Howard Smith, Plymouth Motors

Philadelphia—Sept. 23
Philadelphia Auto Trade Association, 715 North Broad Street: Dinner 6:30 P. M.
Smoker or Get-Together Meeting

S. A. E. Session at Metal Congress

Hotel Statler, Boston — **Sept. 23, 1931**

9:30 A.M.—GEORGIAN ROOM

Chairman, F. P. Gilligan, Henry Souther Engineering Corp.

Heat-Treating Methods and Costs—E. F. Davis, Metallurgist, Warner Gear Co.

Recent Developments in Heat-Treating Ball-Bearing Races—Dr. Haakon Styri, SKF Industries, Inc., Philadelphia

Characteristics of Alloyed Cast Iron—F. W. Shipley, Foundry Metallurgist, Caterpillar Tractor Co.

Discussion—Each Paper will be open for general discussion following its presentation

Members of the Society who attend the National Metal Congress will be entitled to one and one-half return-fare certificates which, together with additional information desired regarding the Congress and Exposition, should be secured directly from W. H. Eisenman, care of the American Society for Steel Treating, 7016 Euclid Avenue, Cleveland. These certificates must be secured beforehand and presented to the ticket agent when purchasing transportation.

Transportation-Meeting Plans

WITH the 9th National Transportation Meeting of the Society, to be held in the City of Washington on Oct. 27, 28 and 29, nearly two months away, the program is almost complete. The nature of the papers to be given at the six technical sessions was referred to in the August issue of the S. A. E. JOURNAL on page 106. It is expected that preprints of virtually all of the papers will be available at the offices of the Society in New York City prior to the meeting, so as to give those desiring to do so an opportunity to prepare discussion on them.

The committee in charge of arrangements for the meeting has been practically assured that those attending the meeting will be received at the White House on Wednesday, Oct. 28, to meet President Hoover. This is an opportunity the members will look forward to with pleasurable anticipation. Plans for a visit to the Bureau of Standards on the same afternoon have been well advanced by Dr. H. C. Dickinson, who has cooperated heartily in developing the program for the meeting. On Tuesday evening a very interesting trip through the motorcoach plants of the Washington Railway & Electric Co., through the courtesy of R. D. Voshall, superintendent of equipment, has been assured by E. S. Pardoe, a member of the Committee on Arrangements.

Transportation Dinner Arrangements

Final arrangements for the National Transportation Dinner, in which both the Washington and Baltimore Sections are cooperating extensively, are rapidly taking shape. The toastmaster will be William P. MacCracken, Jr., recently Assistant Secretary of Commerce for Aeronautics and present Chairman of the Washington Section. The Committee on Arrangements has consummated arrangements with Roe Fulkerson, a well-known magazine writer, to enliven the evening with his entertaining remarks. The high spot of the dinner will be announced later.

Plans for the meeting have been developed largely by the following Committee on Arrangements, cooperating with the Meetings Committee of the Transportation Activity Committee. Representing the Washington Section are: Chairman C. S. Bruce (Past-Chairman of the Section), P. B. Lum, E. S. Pardoe, Treasurer of the Section; G. O. Pooley, J. C. McCalmont, Secretary of the Section, William P. MacCracken, Jr., Chairman of the Section; and C. S. Fliedner, Vice-Chairman of the Section. The Baltimore Section representatives are: A. B. Boehm, Chairman of the Section; Adrian Hughes, Jr., Chairman of the Transportation Meetings Committee; G. E. Hull, Vice-Chairman of the Section; and E. W. K. Williams, Treasurer of the Section.

10th National Production Meeting Program

Book-Cadillac Hotel, Detroit — **Oct. 7 and 8**

Wednesday, Oct. 7

10:00 A.M.—CRYSTAL ROOM

Welding—J. W. Meadowcroft, Edward G. Budd Mfg. Co.

2:00 P.M.—CRYSTAL ROOM

Inventory Control—C. P. Stiffler, Oakland Motor Car Co.

Cleaning and Preparation of Metal Surfaces—F. P. Spruance, American Chemical Paint Co.

Thursday, Oct. 8

10:00 A.M.—CRYSTAL ROOM

Hot Coining—J. H. Friedman, National Machinery Co.

Economic Advantages of Permanent Molding—J. L. Dostall, Holley Permanent Molding Machine, Inc.

2:00 P.M.

Plant Visit. Transportation will be provided from the hotel and return

6:30 P.M.—BALL ROOM

National Production Dinner
Toastmaster—A. K. Brumbaugh, White Motor Co.
Speaker—To Be Announced Later
Electrons at Work and at Play—Phillips Thomas, Westinghouse Electric & Mfg. Co.

Chronicle and Comment

Christening of the U.S.S. Akron

ONE hundred thousand persons, more or less, assembled at one end of an airship hangar in Akron, Ohio, experienced a thrill on Aug. 8 as they saw Mrs. Herbert Hoover christen the ZRS-4, which will be generally known as the U. S. S. Akron. It was an impressive sight, and those who witnessed it were moved to see 221,000 lb. of material, fashioned into a well-proportioned body, floating gracefully in thin air.

The completion of this airship marks an epoch in the evolution of lighter-than-air craft, for the U. S. S. Akron incorporates the very latest advancements along the lines of scientific design and construction and is the largest yet built. Although the ship will be used in connection with Naval operations, the lessons that are to be learned from its behavior will be of tremendous value in the construction of aircraft for commercial enterprise.

Society members extend felicitations to their fellow members, President Litchfield, Commander Hunsaker, Dr. Arnstein, and others who have been largely responsible for the successful completion of this remarkable ship.

Myers Responsible for First Chinese Truck

CHINA'S first truck, the Chung Shan, built at the Industrial Works of the Liao Ning Trench Mortar Arsenal in Mukden, is of particular interest inasmuch as D. F. Myers, who has charge of the work, has been a member of the Society since 1925. It is understood that the major units of the truck are of American manufacture and that S.A.E. Standard Specifications prevail throughout.

The National Aeronautic Meeting in Cleveland

FIVE technical sessions and a Dutch Dinner constitute the program for the Society's 20th National Aeronautic Meeting, which is being held in Cleveland, Sept. 1 to 3. This important event is being carried on in conjunction with the National Air Races. The Aeronautical Chamber of Commerce of America is also cooperating with the Society and its very active Section in Cleveland.

Vice-Presidents Lewis and Nutt and their committees are responsible for one of the most valuable and interesting programs that the Society has ever offered. Carl F. Oestermeyer, Chairman of the Cleveland Section, is superintending the local cooperative arrangements.

Transportation Meeting To Be Held in Washington

OCT. 27, 28 and 29 have been selected by the Motorcoach and Motor-Truck Activity and the Transportation and Maintenance Activity as the days when transportation technologists will meet to discuss their problems in the City of Washington.

Vice-Presidents Buckendale and Glynn, together with their respective committees, have arranged for six technical sessions, two inspection trips, a visit at the White House with President Hoover and a tip-top banquet. Something to look forward to!

Production Members To Meet in Detroit

IT is not too early to make plans to attend the National Production Meeting to be held at the Book-Cadillac Hotel in Detroit, Oct. 7 and 8.

Vice-President Brumbaugh, Chairman Geschelin of the Production Meeting Committee, and their associates have produced a three-session, plant-inspection and dinner program that should appeal very strongly to those who are interested in gathering facts and information of value to themselves and their companies.

Welding, inventory control, cleaning and repairing metal surfaces, hot coining and economics of permanent molding are among the topics that will be discussed technically by men who know.

Rating Committee Selected

A joint committee to study rating with the view of bringing forth some generally acceptable method of rating motor-truck and motorcoach chassis has been selected by Vice-President Glynn, acting on behalf of the Transportation and Maintenance Activity, and Vice-President Buckendale, acting on behalf of the Motorcoach and Motor-Truck Activity, and has recently received the approval of the Council through a mail vote. The appointing of this committee is in accordance with Council action at the June 17 meeting, at which the forming of such a committee was unanimously approved.

The personnel of the newly formed committee is as follows: L. R. Buckendale, Chairman; B. B. Bachman, A. K. Brumbaugh, H. W. Drake, F. K. Glynn, A. H. Gossard, A. G. Herreshoff, M. C. Horine, Adrian Hughes, Jr., A. S. McArthur, C. A. Peirce, W. D. Reese, A. W. Scarratt and J. F. Winchester.

Regarding 1930 Transactions

A leaflet of information regarding the proposed issuance of TRANSACTIONS for 1930 accompanied the Aeronautic Meeting Bulletin that was mailed to all members of the Society early last month. The sending of this material, which included an order blank, was in accordance with the action of the Council authorizing the staff to canvass the membership for the purpose of ascertaining how many members would be willing to subscribe for TRANSACTIONS at a nominal price.

Another order blank will be mailed shortly, with the Production Meeting Bulletin, for the convenience of those members who desire to send in an order but who failed to use the blank previously furnished them. All orders for copies of TRANSACTIONS for 1930 must be received before Oct. 1, 1931.

International Standardization

SEVERAL foreign organizations have for some time been actively engaged in the formulation of standards that apply directly to automotive requirements abroad. Although S.A.E. Standards have been used as a basis for many of these European standards, no close association exists between the Society and these foreign agencies. It is hoped that a more intimate relationship may be arranged for the benefit of all concerned.

Applied Load Factors in Bumpy Air

19th Aeronautic Meeting Paper

By Richard V. Rhode[1]

THE PAPER supplements the paper on Weight Saving by Structural Efficiency[2], prepared by Charles Ward Hall. Mr. Hall's paper was confined to a discussion of the design; Mr. Rhode's paper treats the loading conditions, because their sound establishment is the foundation of a safe and efficient structure. The basic character of the loading conditions is sufficient cause to justify extensive study of their underlying principles, since, in addition, structural failures are occurring which can be traced definitely to inadequate strength requirements and the study of the loading conditions becomes a problem of immediate practical importance, the author states.

Mr. Rhode's analysis is confined to the loading conditions on the wings of airplanes in the non-acrobatic category with particular reference to the total loads acting. In conclusion, he states that there seems to be no reason why design load factors for non-acrobatic airplanes will need to be increased greatly over those now used, but it is evident that load-factor schedules and design conditions can be put on a more rational basis than they are on at present, and this probably will be done when the data become extensive enough to justify such a move.

IN THE PAPER Weight Saving by Structural Efficiency[2], Charles Ward Hall pointed out that "the structural design of aircraft may be conveniently divided into two general parts: the determination of the loading conditions, and the design of a structure to withstand these loads." His paper was confined to discussion of the design; mine is confined to discussion of the loading conditions.

It is apparent that sound establishment of the loading conditions is the foundation of a safe and efficient structure. This simple truth is sufficient cause in itself to justify extensive study of the principles underlying the total loads and their distribution. But add the fact that, with increasing performance and maneuverability, structural failures are occurring which definitely can be traced to inadequate strength requirements, and the study of the loading conditions becomes a problem of immediate practical importance.

The general subject of loading conditions involving, as it does, a variety of questions having to do with all parts of the airplane, is too extensive to treat completely in a short paper; therefore, my discussion will be confined to the loading conditions on the wings. Even in this restricted subject a multiplicity of questions and problems may arise. The loading conditions on the wings, however, may be logically divided into two parts: (*a*) the total loads acting, and (*b*) the distribution of these loads over the surface. I will therefore further restrict my discussion to the total loads acting, which is the more basic part, without reference to the load distribution except to show how the total loads occur at certain values of the lift coefficient for which the load distribution may be determined.

No one yet knows enough about even this restricted subject to lay down a set of design requirements that will guarantee structural safety of the wings and at the same time allow minimum weight in all cases. The National Advisory Committee for Aeronautics is now conducting extensive investigations of applied loads and correlated operating conditions on a large variety of types. We already have obtained a large quantity of data on this subject from which we have arrived, we believe, at a fair understanding of the problem. It is only natural that we should have formed tentative ideas as to the proper loads for which to design. We appreciate, however, that the subject of loads is still controversial and that our information is still too incomplete to justify specific recommendations for the revision of loading requirements. I will therefore avoid expressions of opinion on the subject, but will simply discuss the problem as it appears to us and also our methods of attacking it.

Wing-Loading Conditions

The total load on the wings is usually expressed in terms of the load factor, or the ratio of the total load under consideration to the basic load or weight. If the total load under consideration is the load which is actually experienced or applied in flight, the load factor is called the "applied load factor." It is with this load factor that we are primarily concerned.

It would be desirable, if possible, to place the prediction of probable maximum applied load factors on a purely rational basis. Unfortunately, since the piloting technique plays so large a part in the problem, this cannot be done except to a limited degree. The determination of these load factors is therefore contingent upon reliable measurements taken under a wide variety of conditions, including all maneuvers which are likely to be performed on all types of airplane and also flights through bumpy air. Such measurements, to be of statistical value, must be extensive; but, before we can understand such statistical information, it is necessary to understand the relations between the basic variables

[1] Associate aeronautical engineer, National Advisory Committee for Aeronautics, Hampton, Va.

[2] See S.A.E. JOURNAL, October, 1930, p. 466.

upon which the load factor depends. This is simply a matter of elementary aerodynamics.

Relations between Basic Variables

From the general lift equation it follows that the load factor is

$$n = \frac{L}{W} = \frac{C_L S\ (1/2\,\rho_0 V_i^2)}{W} \qquad (1)$$

or,

$$n = \frac{C_L\ (1/2\,\rho_0 V_i^2)}{W/S} \qquad (2)$$

where

n = load factor
C_L = lift coefficient
L = lift
ρ_0 = standard air density at sea level (mass per unit volume)
S = wing area
V_i = indicated velocity
W = weight

Expression (2) shows that the load factor is a function of three fundamental variables: the lift coefficient, the dynamic pressure—or indicated airspeed—and the wing loading. It also shows that, in considering any one of the terms involved, we cannot forget the others since they are all interdependent. Standard sea-level density and the indicated airspeed are used in the formula rather than the general ρ and the true airspeed. It is important to do this because, from the pilot's viewpoint, the indicated speed *is* the speed and ρ means nothing except that it is somehow "tied up" with altitude. Further, since the indicated airspeed is a direct measure of the dynamic pressure, which is really the important thing, the use of this airspeed in any discussion leads to simplicity.

It is evident, from the expression for the load factor, that we must know at least three of the four inter-related quantities before the fourth can be determined. Hence it seems that, to study probable applied load factors, we must study the simultaneous values of lift coefficient, airspeed, and wing loading which may exist in flight when the airplane is performing its proper function. In practice we do not go at it in this way; rather, we measure the load factor and airspeed directly by means of suitable instruments and then determine the corresponding lift coefficients algebraically. The wing loading in any particular case is of course known.

The load-factor equation can be represented to advantage graphically as in Fig. 1. Since only three variables can be handled conveniently on a graph, the chart shown represents the relations between the load factor, the lift coefficient and the speed for a fixed wing-loading, which, in this case, has a value of 10. For any other wing loading it is necessary to construct another chart or to change the load-factor scale.

On such a chart the airplane normally operates within certain speed limits near the dotted line representing a load factor of 1, and corresponding to level flight through smooth air; but the airplane explores the chart more thoroughly than a mere traversing of the dotted line. On the contrary, no airplane explores the chart completely; that is, no airplane in practice is ever pulled up so rapidly from a dive at V_t (t=terminal) that the maximum theoretical positive load factor is attained and, similarly, the maximum theoretical negative load factor is never attained. However, any practical maneuver or usual flight condition can be plotted on the chart somewhere within the limits of its boundary. Our problem is therefore essentially a matter of establishing a practical boundary line beyond which the airplane will not go in actual operation.

The real limits which apply to any particular airplane are determined in a general way by the function of the airplane. The V limit for a pursuit or fighter airplane, for example, will fall farther to the right than the V limit for a transport airplane which is not called upon to perform fast dives. The n limit for pursuit airplanes obviously will be higher than the n limit for any other type. In addition, pursuit or stunting airplanes may frequently experience inverted-flight conditions which lie well into the negative n area, while others do this to a much lesser extent.

Three Airplane Categories

To clarify the discussion for the present purpose, all airplanes can be divided into three main categories:

(1) *The Acrobatic Category*, defined as the group including all airplanes on which any maneuver may be performed without restriction other than that imposed by the judgment or skill of the pilot or by certain qualities of the airplane itself.

(2) *The Non-Acrobatic Category*, defined as the group including all airplanes for which the necessity for performing any but the mild turns, etc., required to achieve a given destination does not normally arise.

(3) *The Restricted Acrobatic or Intermediate Category*, defined as the group including all airplanes which, for any reason, are likely to be maneuvered so as to impose higher load-factors than those in the non-acrobatic category, but for which the type or severity of the maneuver is restricted

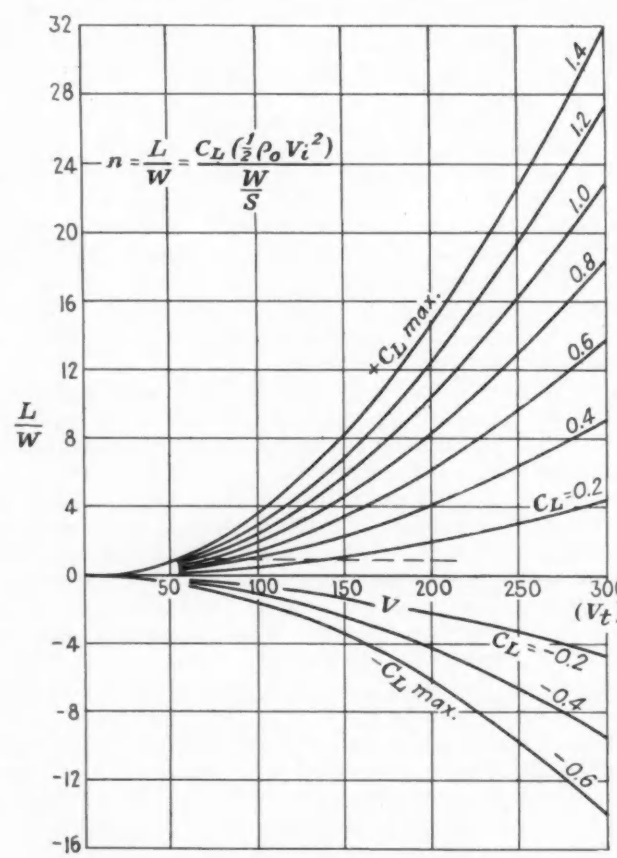

FIG. 1—GRAPHIC REPRESENTATION OF THE LOAD-FACTOR EQUATION

either by mandate or by the function of the airplane so that the group cannot properly be classified as acrobatic.

The acrobatic and intermediate categories, interesting as they are, involve questions which are still highly controversial, and we feel that it would be premature

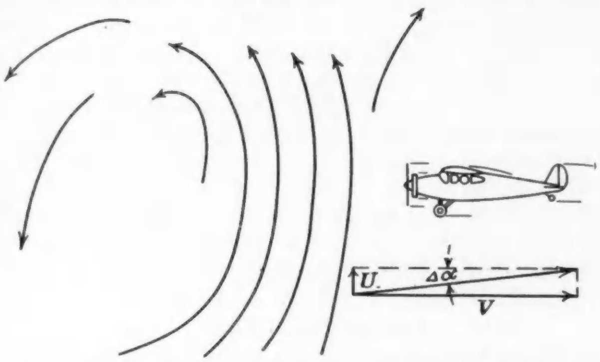

FIG. 2—CONDITIONS PERTAINING WHEN AN AIRPLANE SUDDENLY ENCOUNTERS AN AIR CURRENT FLOWING NORMAL TO THE DIRECTION OF FLIGHT AND IN THE PLANE OF SYMMETRY OF THE AIRPLANE

to give any information at present. It might be said, however, that load factors in the acrobatic and in the intermediate categories are largely a function of the ability of the pilot to withstand and to react to the accelerations, which are proportional to the wing loads. Our tests indicate that the variations in this ability between different pilots are great.

In the non-acrobatic group, which comprises a large number of civil airplanes, the conditions encountered in flying through turbulent or "bumpy" air give rise to the most important load factors.

It can be shown that, if an airplane suddenly encounters an air current flowing normal to the direction of flight and in the plane of symmetry of the airplane, as in Fig. 2, the load factor is expressed closely by the relation

$$n = \cos \Theta + (1/2\, \rho\, a\, U\, V)\, /b \qquad (3)$$

where

n = load factor
Θ = flight-path angle
ρ = air density, (mass per unit volume)
a = slope of the lift curve, $\frac{\Delta C_L}{\Delta \alpha}$ with α measured in radians,
U = vertical velocity of the air current or gust, ft. per sec.
V = initial velocity of the airplane or the speed of flight, ft. per sec.
b = wing loading, lb. per sq. ft.

A more general expression than this could be given, but the equation presented is sufficiently accurate for

TABLE 1—VELOCITIES OF ASCENDING CURRENTS IN THE ATMOSPHERE

	Line Squalls[a]	Thunderstorms[a]	Obstructional Turbulence[b]	Convection Currents[ab]
U, ft. per sec.	44 to 110	44 to 110	10 to 27	7 to 24 or more
Altitude	Up to 4,000 ft.	Up to 20,000 ft.	Varies with terrain	Up to 4,000 ft.

[a] Values taken from meteorological reports.
[b] Values obtained from flight records.

TABLE 2—CHECK ON THE VALIDITY OF THE "BUMP" FORMULA

Run No.	Airplane Type	V_i, M.P.H.	U, Ft. per Sec.
[a]1.a	Biplane Pursuit	101	11.1
2.a	Biplane Pursuit	154	11.2
[a]1.b	Six-Place Cabin Monoplane	101	10.6

[a] Airplanes flown side-by-side.

practical purposes and it represents the most severe and therefore the most important conditions.

Normally, the airplane will be in substantially level flight. Cos Θ is therefore usually equal to 1, and any ordinary deviations from level flight will not greatly affect its value. The slope of the lift curve for ordinary airplanes lies within fairly narrow limits and depends upon the effective aspect ratio. For biplanes its value is about 4.0 and, for monoplanes of high aspect ratio, about 4.5. If ρ is assumed equal to ρ_0, we may include it in a constant and find ourselves confronted with the three important variables, U, V, and b; however, U and V must now be considered as "indicated" velocities.

For any given design, the wing loading and the probable speeds at which the airplane will travel usually are known; therefore, we must determine the probable values of U, or the vertical velocity components of the air currents which will be encountered in flight. In general, two ways of doing this are available. First, an idea of the structure and motions of the atmosphere can be gained by a study of meteorological reports, bulletins and textbooks. Second, measurements of acceleration and airspeed can be made on an airplane of known characteristics flying through bumpy air, and the data inserted in the formula and "back-figured" to determine the *effective* value of U. The National Advisory Committee for Aeronautics has made use of both methods. In addition to flight tests on its own airplanes at Langley Field, accelerometers have been sent out in a few instances to operating companies and used to record the accelerations obtained on regular scheduled trips, over flat country and over mountains, and in a variety of weather conditions. The essential facts which have emerged from the study thus far are summarized in Table 1.

Different Types of Air Disturbance

In explanation of the different types of disturbance listed, line squalls and thunderstorms are manifested by violent convection currents and involve conditions so severe that they must be avoided. They are not conditions for the structural designer to consider, but for the weather forecaster associated with air-transport operations. "Obstructional turbulence" is a term which I apply to the kind of rough air caused by relatively high wind flowing over an uneven surface. Over relatively flat country broken by woods, occasional hills, tall buildings and the like, this type of disturbance, according to Gregg, extends about four times the height of the obstruction above the mean level of the ground. As I have used the term, it applies to mountainous regions as well as flat country, and the disturbances may exist to considerable altitudes. The term "convection currents" means the milder sort usually associated with variations in the local heating of the terrain and particularly noticeable on hot summer afternoons.

The values given in Table 1 probably can be considered as associated at times with vertical currents having fairly sharply defined boundaries. To check the validity of the "bump" formula, which assumes an in-

finitely sharp boundary, flights were made on two different airplanes at a few speeds through a practically constant bump which we discovered near Langley Field. Back-figuring the data through the formula gave nearly the same value of U, for all cases, as shown in Table 2.

Table 2 applies only for one particular bump; but acceleration records taken in rough air always show that the peak load is reached in a small fraction of a second, which is an indication that, when bumps occur, they may be quite abrupt. This simply means that the change in angle of attack upon encountering a bump may be considered as virtually instantaneous and as consisting mainly of the angle whose tangent is U/V. It is therefore believed that the formula for the load factor on encountering a bump may be used directly with such data as are given in Table 1.

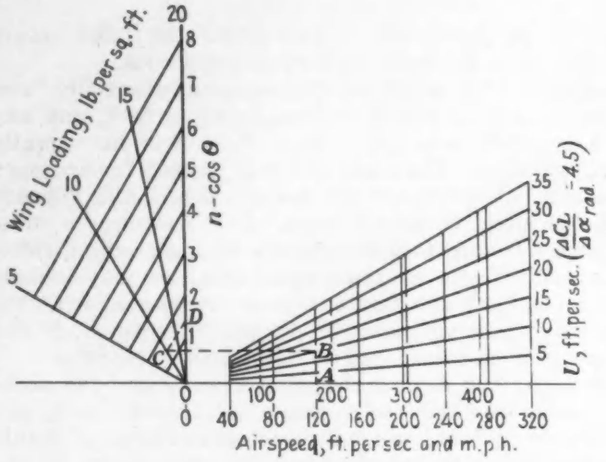

FIG. 3—APPLIED LOAD FACTORS IN "BUMPY" AIR

A chart can be constructed, such as that shown in Fig. 3, which will show the maximum load factor to be expected on any airplane flying at any speed through rough air of any degree of severity. But the chart in Fig. 3 applies only to airplanes having a lift-curve slope of 4.5. For example, consider a monoplane having a wing loading of 10 and cruising at 120 m.p.h. Assume that it encounters a current having a vertical component of velocity of 15 ft. per sec., a probable value for "average rough air." Starting at point A at 120 m.p.h., read up to point B corresponding to $U = 15$ ft. per sec. and the representative monoplane aspect ratio. Then read to point C at the left on the line corresponding to a wing loading of 10, and thence diagonally upward to the load-factor scale. The answer is an applied load factor of 2.42 when cos Θ is taken as unity as in level flight. This is a good representative case and the answer obtained corresponds quite closely with experience.

A similar example for an airplane having a more uptodate performance is that of a monoplane having a wing loading of 10 and a speed of 160 m.p.h. and encountering the same bump as in the previous example. The load factor is 3.1; but, with a wing loading of 15, it is reduced to 2.3. If we speculate on the future and assume a monoplane having a cruising speed of say 210 m.p.h. and a wing loading of 10, the load factor for U=15 ft. per sec. will be 3.5; but, with a wing loading of 15, the load factor is reduced to 2.6.

These examples illustrate the probable maximum applied load factors to be expected at various speeds and in various airplanes in an atmosphere which can be considered not extraordinarily rough. Vertical velocities of ascending currents may, however, exceed 15 ft. per sec. under weather conditions which would not interrupt flying schedules, although they are of less frequent occurrence. We have evidence that vertical velocities as high as 30 ft. per sec. may be encountered at times. These higher values are believed to be more common in the mountains, although, under certain conditions, they can be expected over any part of the Country. For example, Polar air descending from the North and displacing relatively warm air may set up intense convection currents at the front of the Polar mass, the condition giving rise to a mild line-squall. If the line squall is severe, it will be avoided; but the line squall often is not well enough developed or is not sufficiently severe to give warning. Such cases must be considered as occasional possibilities.

Design Conditions

The "bump" chart does not indicate the nature of the load distribution coincident with the applied load factor. To determine the proper design conditions, that is, whether the maximum load factors occur at high or low angles of attack, it is necessary to solve for the lift coefficient from the basic load-factor formula when the load factor, the speed of flight, and the wing loading are known. The design conditions can be shown conveniently on the basic load-factor chart.

Let us assume an hypothetical example of a monoplane having a gross wing loading of 15, an estimated high speed of 160 m.p.h. and a cruising speed of 135 m.p.h., and that the pilot is obliged by mandatory requirements not to exceed 15 per cent in excess of the high speed, or 185 m.p.h. So much for the performance of the airplane. Now let us say that a vertical velocity in gusts equal to 15 ft. per sec. occurs with sufficient frequency so that the airplane can be expected to encounter this current at any speed up to the limiting speed of

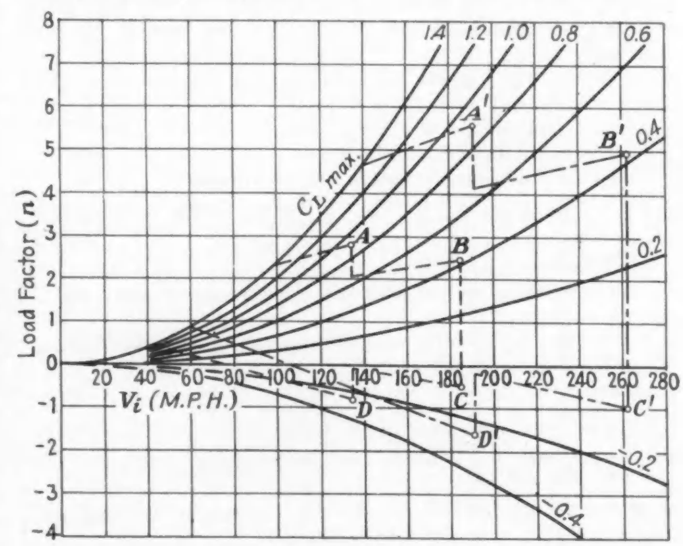

FIG. 4—LOAD-FACTOR CHART FOR A TRANSPORT AIRPLANE

The Wing Loading Is 15 Lb. Per Sq. Ft., the Cruising Speed is 135 M.P.H., and the Allowable Maximum Speed Is 185 M.P.H.

185 m.p.h. Also let us say that more severe bumps—with U=25 ft. per sec.—may be encountered a few times within the life of the airplane, but that these bumps are so infrequent that they can be assumed to occur only at the most common flying speeds; namely, cruising speed or less.

On this basis the chart shown as Fig. 4 can be drawn to show the limits of the probable applied load factors and the associated lift coefficients. The area enclosed by the dotted line represents all the probable conditions which are likely to be encountered in flight on the basis of our original assumptions. Points *A*, *B*, *C* and *D* usually will be found to be the critical conditions, although not necessarily so. If a factor of safety of 2 is applied to give the design load factors, the boundary line is expanded to the dot-dash line shown.

I emphasize again that the actual values of the load factor and the values of *U* which have been used in the illustrations cannot be taken as final, because of the relatively small amount of data we have on the subject to date. The best I can say is that it does not appear that it will be safe to assume much lower values of *U;* however, it does seem that design load factors can safely be kept relatively low on transport or cargo-type airplanes if the airplanes are flown at sufficiently high altitudes to avoid the worst bumps, or if they are flown with proper regard for the other variables that affect the loads. It may be found feasible, later on, to differentiate between transport airplanes which are to be used on flights over flat country and those which are to be used over the mountains, designing the former group to withstand less severe loads.

In general, there seems to be no reason why design load factors for non-acrobatic airplanes will need to be greatly increased over those now used. At the same time it is evident that load-factor schedules and design conditions can be put on a more rational basis than they are on at present, and that this probably will be done when our data become extensive enough to justify such a move.

THE DISCUSSION

Ralph H. Upson[3]:—Mr. Rhode has quoted Charles Ward Hall's treatment of load factors as being generally divisible into two parts, but we might make a third division which is rather important. Dividing the subject into three parts, we would have (*a*) the determination of the load-forming conditions; (*b*) the choice of airplane characteristics to suit these conditions best; and (*c*) the design of a structure to carry the resulting loads. Mr. Rhode has mentioned one fundamental variable having to do with the design of the airplane as a whole, namely, the wing loading, and assuming that the speed and the wing-lift curve are substantially fixed; but this one characteristic would hardly justify making a separate classification of the subject in its favor. However, other means are available for adapting the airplane design as a whole to the purpose of better coordinating the weather conditions with the structure which actually has to carry the load, and that is the added condition (*b*) that I have introduced.

According to the formula that has been suggested here for non-acrobatic planes, the size of the plane as such would have no effect whatever on the result, except that pilots of large transport airplanes might consider the load factor more carefully and possibly fly at higher altitudes. For the lower load factors actually used in large airplanes, is it not perhaps a better excuse to admit frankly that, for any reasonable payload, it is hardly possible to design a large airplane with the same load factors that are required for small airplanes; or, in other words, the high load-factor can be obtained in a small airplane with much less sacrifice than it can be in a large airplane.

It seems, however, that airplane size does have some fundamental effect. I know of no accurate data on this subject, but it is quite common experience that a large airplane is subjected to less severe loads as an average, even under the same conditions, than is a small airplane. I believe the reason lies to some extent in the fact that a large airplane almost invariably has a larger tail-arm length, which is one of the vital factors entering into several of the terms of the complete stability equation.

In introducing the subject of stability, I can best indicate what I mean by reference to the old-style airplane which very often was positively unstable. In that case it is very obvious that on meeting a sudden up-gust of wind the plane, if an unstable one, will tend to increase its angle of pitch to an attitude at which the load factor is even greater than would be given by the formula. Thus the force has a tendency to magnify itself. Fortunately, that type of plane is now banished by the Department of Commerce rules; but, even with the normal, longitudinally stable airplane, a tendency still exists for the pitch momentarily to set itself at an angle which increases the force that acts upon the wings due to the relation between the wing section, the center-of-pressure travel with respect to the center of gravity of the machine as a whole, and the distance between the wing and the tail of the plane, which introduces a time element or a lag within which the plane momentarily goes to a worse angle of attack relative to the gust that it meets. It seems possible that this factor may be responsible for the seeming justification found in the other assumption Mr. Rhode made; namely, that of an ideally sharp gust which, of course, never actually exists.

It is entirely possible by proper design to reduce this element of lag in the action of the airplane. For example, although the front elevator as ordinarily understood would make the condition worse, it seems to be possible by proper proportioning of the surface and of the movements to get a design in which an anticipative condition will exist with regard to the stability in a gust rather than a lagging one.

Finally, there is the entire field that is concerned with the use of yielding elements in the wing structure. Conspicuous examples of this are Autogiro rotor blades and the Waterman type of airplane wing. Installing shock-absorbing elements in the wings themselves in some form accomplishes at least three qualitatively worthwhile effects. First, the wing acts as a simple shock-absorber to carry the brunt of the first shock, assuming that a very sudden gust can occur, which spreads the acceleration resulting therefrom over a longer period and makes it less severe, just as any ordinary shock-absorber does. Second, it bridges the gap that is required for the bump to pass from the wing to the tail of the plane, thus giving the tail a chance to do its work and stabilize the plane to meet the gust. Third, by proper choice of the kind of movement that

[3] M.S.A.E.—Aeronautical engineer, Dearborn Building, Dearborn, Mich.

is allowed, it is possible to get a very direct reduction in the force that is imposed by the deflection itself. By merely pointing out these possible lines of attack, I want to emphasize the importance of that third element of the subject, which hitherto has been comparatively neglected, and also to point out the incidental importance of keeping the weather conditions which are responsible for the forces and the forces themselves well separated.

Load-Factor Ratio May Vary with Airplane Size and Type

R. V. RHODE:—Concerning the third condition, Mr. Upson's point is well taken. An example of how his point has been overlooked is to be found in the application, in some cases, of highly cambered wing-sections to airplanes intended for fast dives. If the third point had been taken into account, these airplanes would have been designed with wing sections more closely approaching the symmetrical, thus giving rise to much less severe loads on the structure in a given dive.

Mr. Upson's desire to admit frankly that it is hardly possible to design a large airplane to the same load factors that are required for small airplanes is evidence of an honesty of thought that I admire. But we are not at issue on this point. The applied load factor and the design load factor do not necessarily bear the same ratio to each other as the size of the airplane increases or as the type differs. While in my illustration of the loading conditions on a transport airplane I used a factor of safety of 2 to give the design load factor, I am nevertheless fully aware that often the intended minimum factor of safety is as low as 1.2 for the reason that Mr. Upson intimated.

Concerning the effect of the size of the airplane on the magnitude of the bump, there is room for further study. Thus far, we have really only scratched the surface of the whole question. Our most immediate problem is to find out something about the magnitudes of the applied load factors in bumpy air, and we are doing this at present by measuring accelerations in flight on various types of airplane. It has appeared that, for the time being at least, these data could be put into a more useful form by reducing the accelerations to "effective" vertical velocities of the gusts on the basis of the formula presented. The effects of size and many other elements are not being left out of consideration, and we hope to make a more complete study of conditions in rough air before we are through.

A MEMBER:—Will Mr. Rhode state his understanding as to the Waterman wing? I believe it was tested by the N. A. C. A., with a shock-absorber in the wing system which changes the angle of incidence as the load increases.

MR. RHODE:—To my knowledge there was never any test made on the Waterman wing specifically for the purpose of determining the shock-absorbing characteristic of the wing when flying through rough air. I believe the wings were locked in position and the airplane subjected to so-called abrupt pull-ups at various speeds, and the accelerations were recorded. After that, the wings were unlocked so that the shock-absorber device would function as intended, or at least give it opportunity to function, and these pull-ups were repeated. I had nothing to do with the tests, and am not familiar with the actual accelerations that were obtained, but I understand that the accelerations in the latter condition were virtually the same as they were in the former condition. The opinion was that this particular device did not answer the question completely.

CHAIRMAN G. W. LEWIS[4]:—Mr. Upson stated that he thinks there are no sharply defined rising air currents. A number of instances have come to my attention in which they are very sharply defined; that is, where the airplane would change altitude suddenly from 1000 to 4000 ft. But, as Mr. Rhode has pointed out, it is a meteorological problem and the severe weather conditions which would be handled by that particular division of the airline. However, it is my understanding that many of the transport companies are attempting to obtain pilots who appreciate that bumpiness is not a pleasure to the passenger, and that they are flying the airplanes with the maximum of comfort for the passenger. Some railroads advertise that their trains are more comfortable because, when the engineer stops and starts, he uses more care and more time so as to prevent jerking. The same thing may apply to the operation of an airplane on an air-transport line. A great deal depends upon the pilot on how an airplane is flown under adverse weather conditions.

Loads Imposed by Horizontal Air Pulsations Not Yet Studied

EDWARD P. WARNER[5]:—Mr. Rhode has spoken at length of the vertical currents and has given numerical values which, so far as I know, are unique in the literature and are of great importance. I think we all take it for granted that horizontal currents are of much less importance, but they may not be entirely negligible. We know that the velocity and direction of winds are extremely pulsating, and they are interesting in that they lead us to reverse conclusions drawn from the vertical currents about the effect of speed on roughness of flight. The higher the speed is, the smoother the flight is if horizontal pulsations are present. What evidence is available on the possible magnitude of those pulsations and the loads they may impose in very gusty winds?

MR. RHODE:—It is impossible for us to know, when an airplane goes up and these acceleration records are obtained, whether the bumps that it gets are horizontal pulsations or vertical pulsations. We have neglected the horizontal pulsation because, theoretically, what you say is true. With increasing speed of flight the effect of the horizontal pulsation becomes relatively of less importance, and from a theoretical viewpoint the effect of the horizontal currents is very much less than the effect of the vertical currents in any case. I know of no horizontal pulsations that have been measured at great altitudes. All of the measurements that I have seen have been taken close to the ground. These so-called gusty-wind investigations are always associated with conditions very close to the ground, and I do not know what the plane might encounter when flying. There is a condition where two adjacent wind strata flow in different directions or at different velocities, thus causing a region of turbulence between them that involves horizontal pulsations, but I do not know what they are. We have very little information on this whole subject.

[4] M.S.A.E.—Director of aeronautical research, National Advisory Committee for Aeronautics, City of Washington.

[5] M.S.A.E.—Editor of *Aviation*, McGraw-Hill Publishing Co., Inc., New York City.

Air-Cooled Cylinder-Head Design

Semi-Annual Meeting Paper

By Roland Chilton[1]

THE TWO MAJOR REQUIREMENTS for good cooling of an air-cooled cylinder-head are (*a*) adequate conductivity from the zones of maximum heat-flow, that is, the spark-plug bosses and the exhaust-valve seats, elbows and guides, to a sufficient area of finning, and (*b*) the maintenance of a high-velocity air-flow over the entire length and depth of all fins. Solution of the problem of (*b*) depends upon many items in the engine installation outside of the cylinder-head.

A limit to possible power output of the cylinder is set by detonation, which, with a given fuel, depends upon the cylinder-head temperatures. As these temperatures are the basic index of operating conditions of air-cooled engines, the author states that a head thermocouple instrument should be standard equipment on every airplane, and pilots should be trained to respect head temperatures as much as they now respect oil pressures and temperatures. Much higher ratings and cruising speeds could then be used with assurance under all normal conditions, because the head-temperature indication will give warning before harmful conditions develop.

Much interesting and valuable supplemental information is brought out in the discussion. Rate of impact of the air on the fins is believed to be an important factor in cooling. Apparently small design changes to reduce air resistance can have as much effect in increasing speed as an increase of many horsepower in the engine. Fuels of 80-octane antiknock rating, if generally distributed, would enable the supercharged-engine rating to be increased one-third without changing anything but the blower ratio and would lower the piston temperature, reduce some of the stresses in the engine parts and be less severe on the lubricating oil. It is said to be better to boost the power output by increasing the supercharger pressure a moderate amount and increasing the piston compression slightly than to accomplish the result by either the piston or the supercharger alone.

Emphasis is placed on cylinder-head temperatures as a basic indication of safe engine-operation. A thermocouple attached to the rear spark-plug of the cylinder that becomes hottest warns the pilot when to reduce the throttle opening. Questions regarding the spark-plug cooler and radio shield are raised and answered. The question of cylinder-head design to get intimate thermal contact of cooling fins and the best air-flow around the parts is debated. One discusser points out that the use of longer pistons would permit of more piston-rings which would aid heat-flow to the cylinder-walls, but the reason for using short pistons is that the engine diameter must be reduced to the minimum. Poor mixture distribution rather than detonation is said by one discusser to be responsible for most of the piston trouble.

"AIR-COOLING" has become the accepted term for the dissipation of engine-cylinder heat to the atmosphere from radiating elements in direct thermal union with the cylinders and cylinder-heads, as distinguished from so-called "liquid-cooling," wherein the heat is conveyed from cylinder-jackets to a separate radiator by circulation of a liquid.

The area of radiation surface required per unit of heat dissipation, with a given effective air velocity, is an inverse function of the difference between the temperature of the radiating surfaces and that of the outside air. Fortunately, the temperature of the radiation surface is limited in liquid-cooled engines by the boiling-point of the transfer medium, whereas, with direct air-cooling, it should be limited by the consideration that excessive head-temperatures are fatal to high output and good durability of the engine. In spark-ignition engines of modern designs, detonation sets the limit to the safe output, and the tendency of fuels to detonate depends upon the combustion-chamber temperature.

Power Ratings Limited by Fuel Knock-Value

The iso-octane number is the best index that has been developed for the antiknock rating of fuels. The aviations fuels sold at many airports are worse in this respect than the Ethyl standard motor gasolines obtainable in every city and village in the United States. The worst examples of aviation fuel are as low as 53 iso-octane rating, as against approximately 75 iso-octane for the good standard motor gasoline.

Spark knock from bad fuel in high-compression automobile engines is so obvious that no one will use such fuel; but, with the exhaust noise and the other noises now incident to flight, most aircraft pilots cannot tell the difference between good and bad gasoline, and aircraft engines are often operated on fuels that would not be tolerated in a high-powered car.

Power ratings of commercial-aviation engines have to be limited to power outputs that the engine will stand on the worst current fuels. For example, in the case of the Wright Whirlwind E-Series engines, this is about three-fifths of the rating possible on 1931 Army specification fuel. At present we rate at 300 hp. one model that has been endurance-tested at 375 hp. on

[1] M.S.A.E.—Consulting engineer, Wright Aeronautical Corp., Paterson, N. J.

automobile Esso, which, as regards antiknock, is superior in that proportion to the aviation fuel that may be inflicted upon the engine in service.

These remarks on power ratings apply to supercharged engines, the power output of which can be regulated merely by the selection of a supercharger gear-ratio that will give an over-all compression-ratio up to the limit of incipient detonation set by the fuel that may be encountered in service. Naturally aspirated engines are susceptible to smaller power increases by increase of the compression ratio, which is similarly limited by the fuel.

How Head Temperatures Affect Power Ratings

Assuming a known low limit to the iso-octane rating of the fuel, which is a large assumption to make at present, the limit to engine output depends upon the combustion-chamber temperatures. These are *not* the temperatures read on the thermometers in liquid-cooled engines. With Prestone at 300 deg. fahr., the spark-plugs and exhaust valves often are as hot as in air-cooled engines—"red hot" is no exaggeration in some cases—and these hot parts limit the non-detonating power output, that is, the maximum permissible output and the durability. As the power output of an engine is increased by steps, the cylinder-head temperatures stabilize at higher levels until detonation develops; thereupon the detonation increases the temperature and the higher temperature increases the detonation until the engine is damaged unless it fortunately slows down.

Apart from setting the limit to power output, excessive cylinder-head temperatures and the accompanying detonation are the cause of most of the cylinder-head and valve troubles that occur in modern engines, including damage suits on account of the dropping of entire cylinder-heads over cities.

The relation between cylinder-head temperature and detonation is like the question of the chicken and the egg; it is difficult to say which precedes the other. For every set of conditions, however, a direct relation exists between the engine output (b.m.e.p.) and the cylinder-head temperatures, which increase together up to a definite critical point, whereat the temperatures rise suddenly and the power falls off. The object of cylinder-head cooling is to bring this critical point high enough to make possible the highest output of power.

Air-Flow Should Be Parallel to Fins

The ideal condition for air-cooling is represented by a streamlined body having longitudinal fins and a truly axial air-flow, which presupposes absence of interference from adjacent bodies. None of these conditions prevails with air-cooled cylinder-heads, although most of the research on heat dissipation from finned surfaces has been based on conditions under which actual velocity over finned surfaces has borne a close relation to the general air-velocity.

Such a relation is lacking in unbaffled engines, as most of the airstream misses the leeward part of the finning and the entire flow is much disturbed. For example, a "flag" placed on a cylinder-head behind a normal tractor propeller will show that the air-flow diverges by 45 deg. or more from the axis of the free stream. This is the usual effect at the front "corner" of a non-streamlined body such as an uncowled engine, and it is aggravated by the centrifugal displacement of the airstream by the propeller hub and the unpitched roots of the propeller blades. In geared engines those cover most of the diameter of the engine, hence good cooling on the ground at full throttle is almost impossible with any unassisted propeller. A ring cowl, brought as close to the propeller as possible, helps to entrain some of this diverging air-flow and redirect it toward parallelism with the cooling fins. It seems obvious that air-flow at an angle across the fins will have very poor cooling efficiency, since under these conditions each fin shields its neighbor.

Temperature Reduced by Baffles and Cowling

A rotary nose-cowl embracing the unpitched part of the propeller will entrain all of the otherwise divergent flow and utilize the centrifugal action to augment the total air volume impinging upon the engine. Such a large spinner presents some mechanical difficulties, toward the overcoming of which recent patent applications have been directed. Initial experiments have given encouraging results in conjunction with baffles aimed at forcing the air to wash the entire length and depth of every fin. Temperature reductions of 100 deg. fahr. have been realized in tests by means of the baffles on uncowled engines, and further reductions are indicated from the increased velocities due to the spinner cowl.

Such fitments should not be dismissed as tinware, even by those who are satisfied with the present cylinder-head temperatures, because, if this satisfaction were justified, the baffles would make possible a reduction in the fin weight and in the necessary cowl outlet-slot areas, which at present detract from the streamline ideal even in the best N.A.C.A.-type cowlings. In one instance the high speed of a fast N.A.C.A.-cowled airplane was increased by 8 m.p.h. by including the baffles, because they reduce the total quantity of air emerging from the outlet slot. The outwardly diverging exit flow that often is characteristic of these cowl designs is, in my opinion, a source of unnecessary drag.

That all the air passing beyond the tops of the fins between the cylinders and rocker-boxes is wasted as regards cooling is obvious, and extra drag is induced in forcing this surplus air through the cowling. With complete baffles restraining the air-flow to the finned periphery only, a J-6 engine has been well cooled through a 15-in.-diameter entrance hole, which corresponds to a 1-in.-wide exit annulus, giving an almost perfect streamline when the entrance is in the spinner ahead of the propeller.

Fin Arrangement and Spark-Plug Cooling

Air-cooling of cylinder-heads involves two major problems. The first, touched on in the foregoing, consists in arranging the fins so that the air-flow is directed to wash over all the cooling surfaces. This presents more difficulties than the companion problem of designing the head so as to give adequate conductivity from the hot-spots to a sufficient area of finning. The exhaust-valve seats and guides and the region of the spark-plugs are the zones of concentrated heat-flow, and the area of fins in good thermal contact with these regions will determine the valve and spark-plug durability at high power-output. In the present Cyclone engines having salt-cooled valves, which greatly augment the heat-flow to the stem, the bearing surface of this part will show merely a blue color after running at a mean effective pressure of 160 lb. per sq. in. on good fuels, indicating a stem temperature of the order of 650 deg. fahr.

Spark-plugs have been dealt with by means of the Wright spark-plug cooler, which comprises a shell surrounding the plug and incorporating the spark-plug bushing so as to be in intimate thermal contact with the cylinder. This shell is covered with fins and is the basis of a neat and water-proof spark-plug shielding system. The spark-plug cooler with shielding is shown in Fig. 1. Approximately 100-deg. drop in rear spark-plug temperature has been achieved by this means, with the plug entirely covered. Measurements of spark-plug-point erosion have shown that a rear plug fitted with the cooler increases in gap less in 50 hr. than does a bare front plug in 10 hr.

Valve ports, piping and other elements that must be associated with the cylinder-head unfortunately create a divergence from approximate streamline form, hence the conformation of the fins so that they shall receive good air-flow in spite of these protuberances is a problem on which further research is needed. Experience has shown that a true streamline body with axial flow would have adequate cooling for cylinder-head purposes with much less fin area than is now used in actual head designs. It is also known that optimum cooling and lightness are obtained with thinner and much more closely spaced fins than is at present dictated by foundry practice.

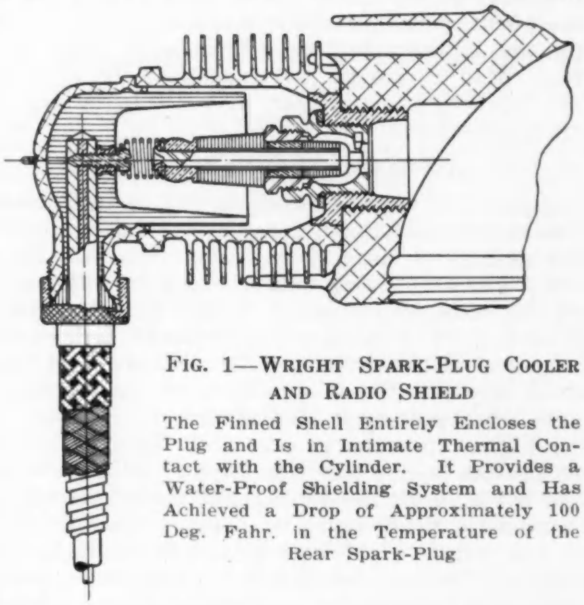

FIG. 1—WRIGHT SPARK-PLUG COOLER AND RADIO SHIELD

The Finned Shell Entirely Encloses the Plug and Is in Intimate Thermal Contact with the Cylinder. It Provides a Water-Proof Shielding System and Has Achieved a Drop of Approximately 100 Deg. Fahr. in the Temperature of the Rear Spark-Plug

Rear Exhausts Simplify Cooling Problem

The controversy as to front and rear exhausts has complicated the situation on account of the desire to build a cylinder-head that is adaptable to both systems so as to meet each demand. This has involved side exhaust-outlets to which elbows for either front or rear exhausts can be applied. When such elbows comprise finned aluminum castings, they abstract some additional heat from the head, whereas with unfinned steel pipes, which run red hot, the heat-flow is from the pipe to the head. These elbows, however, present added obstruction to the air-flow to the rear of the cylinders.

The first complete exhaust systems to be delivered by engine manufacturers as standard equipment were of the front type, whereas provision of the manifold for rear exhausts was left to the airplane builder. This has prejudiced some persons against the rear system, which often was unsightly. I believe that the rear-exhaust system makes cooling of the cylinder-head easier, because the pipes and elbows then present a minimum of interference to the air-flow.

With respect to the research on air-cooling now being initiated by the National Advisory Committee for Aeronautics, it is suggested that the tests be made on actual cylinder-heads with adjacent cylinders on either side, all equipped with the actual inlet and exhaust pipes and other obstructions that are present in service. If heat-flow and air-flow explorations could be made on heads of several different types, the way for further improvement would be indicated. The test set-up should simulate the interference due to the propeller and the engine nose. This latter usually is provided with a nose cowling and shutters, in the expectation that the crankcase cooling can be controlled by this means. In practice, on the ground, the air-flow through the shutter openings usually is forward from the engine to the propeller, and in many service installations the temperatures of the cylinder bases and of the oil increase with the shutters open. The belief is now accepted that such cowlings, from which nine cylinder-heads stick out, do not reduce the drag although they may look like a streamlined engine nose.

Head Temperatures an Index of Operating Conditions

Relatively few installations have as yet been equipped with head thermocouples, notwithstanding our efforts to convince all operators that cylinder-head temperatures are the basic index of operating conditions, with which oil temperatures have very little connection. Most pilots still regard the oil temperature as an indication as to whether the engine is running hot or cold. Oil-temperature readings that would terrify most pilots are safe with normal cylinder-head temperatures. When a head-temperature indicator is consistently used, the amount of full-throttle running that can be done on modern engines without developing excessive temperatures is surprising; and the occasional conditions of bad fuel, lean mixture, heavy loads or low humidity, when detonation would result, are immediately brought to the attention of the pilot and damage to the engine is avoided.

If these remarks will help toward getting all military and transport organizations to operate engines with due regard to cylinder-head instead of oil temperatures, they will have had a useful effect.

Incidentally, if the pilot should ever read the temperature of the oil as it comes directly from the pistons and main bearings, he would make an emergency landing at once. What he reads on most installations is the mean temperature of all the oil returning from the engine, which usually includes at least 50 per cent from the bypass valve, which has not been heated at all. Sudden development of detonation may damage an engine before any abnormal readings are given at the oil-temperature indicator.

Factors That Must Be Controlled

Taking good design and mechanical condition for granted, the following items must be controlled in order to determine the maximum permissible brake mean effective pressure, which must be held below the point at which the cylinder-head temperatures become high enough to cause detonation:

(1) Iso-octane number of fuel
(2) Mixture strength
(3) Mixture temperature
(4) Intake-air humidity.

The better the cooling is, the higher is the brake mean effective pressure that can be carried under any set of conditions. The best cooling values now obtainable under controlled conditions permit safer power outputs approaching twice the present commercial ratings of unboosted engines without unduly stressing a well-developed design. The worst condition that might occasionally be encountered in service on one of the four items alone will damage a moderately ground-boosted engine, and a combination of bad conditions will quickly spoil even those examples deliberately designed for low brake mean effective pressure.

Most of the items may be brought to the danger line by faulty operation or installation, but in every case a cylinder-head thermocouple will warn the pilot who has been properly instructed and equipped that unusual conditions require reduction of the throttle opening. With such equipment on engines provided with good cylinder-cooling, the pilot will find that the traditional throttling-back by 200 or 300 r.p.m. for cruising is quite unnecessary under normal conditions, in which must be included a fuel of a knock rating suited to the supercharge pressure of the engine.

Substantially ground-boosted engines at the usual cruising speeds develop about the same manifold pressure, and therefore power output, as do unboosted engines at full throttle, and this extra performance may be enjoyed with complete confidence if a head-temperature indicator is used. Cylinder-head temperatures developed in customary operation are perhaps the best index of the progress in air-cooled cylinder-head design. These temperatures have been reduced in the last few years in round numbers from more than 500 deg. fahr. to about 350 deg., in spite of increased power-outputs; in fact, the reduction in temperatures has made possible the increased outputs.

Excessively lean mixtures are, next to bad fuel, the commonest cause of detonation and the accompanying dangerous cylinder-head temperatures. This effect can easily be observed on a boosted engine in a cabin airplane with a closed exhaust, so that detonation can be heard, and having a normal carbureter setting of about 0.6 lb. per hp-hr. at full throttle and 0.55 lb. per hp-hr. at cruising speed. On poor fuel, detonation can be induced by protracted full-throttle operation near the ground; and, as the throttle is then slowly pulled back, the initial effect is to increase the detonation as the lean-mixture range is entered with the heads hot. The heads require a low cruising engine-speed for a few minutes to cool off. With a boosted engine of modern head-design this effect usually cannot be demonstrated by a full-throttle climb starting with moderate head temperatures because the manifold pressure will be reduced by altitude before the heads become hot enough to cause detonation. Thus the throttle may be left wide open on boosted engines on indifferent fuel when climbing promptly to about 3000 ft., provided the head design gives good cooling.

Cylinder-Barrels Present Few Cooling Problems

The cooling of cylinder-barrels calls for little comment because the heat-flow is relatively small, a large portion of the heat coming from the piston-head, which is cooled by conduction to the cylinder-walls, while the barrels are free from interfering projections. The thin and closely spaced fins indicated by theory are proving efficient in practice, and, when the technique of head fabrication makes their use possible for this more important part, lower head-temperatures will be realized.

Unequal air-flow is the difficulty with cylinder-barrels, as with heads, and it cannot be cured by researches into fin design. Deflectors to direct the air around the back of the cylinders seem necessary at high outputs to guard against piston trouble from the cylinder distortion which follows unequal temperatures. These troubles are aggravated in cylinder-barrels by the relatively low conductivity of the metal. Cylinder-head cooling would be much more difficult were it not for the high conductivity of aluminum, as is nicely illustrated by the Wright spark-plug coolers, the effect of which on wall temperatures is apparent for 1 in. around the spark-plug bushing.

Much of the large total heat-flow to the heads occurs during the exhaust stroke, and most of this is to the exhaust-valve seat and the port beyond, including the valve-guide boss. The necessary cooling does not represent any loss in thermal efficiency; and, as low-temperature seats and guides will moderate the temperature of the largest air-craft-engine valves, every effort should be made to secure the maximum of effective finning at these points.

Moderate valve temperatures then depend on wide exhaust-seat contact and the minimum stem exposure below the valve-guide boss. Most valve troubles, including head corrosion, which usually is blamed on Ethyl fluid when this is used, are avoided by moderate valve temperatures.

An Automatic Throttle-Stop Needed

Supercharged engines usually are rated in Europe on the basis of sea-level operation on manifold depressions corresponding to natural induction, whereas in this Country engines having superchargers are tested and rated for sea-level operation at full-throttle manifold pressures of 2 to 6 in. of mercury, the higher pressures being permissible only in operations where good fuel is assured or where the pilots can be trusted strictly to observe head-temperature indications.

For higher supercharge pressures the usual practice is to provide a throttle stop beyond which the pilot should not go until the appropriate altitude is reached. An automatic throttle-stop is needed that will always limit the manifold pressure to the point of incipient detonation. Devices responsive to manifold pressure, cylinder-head temperature and peak explosion-pressures are being tried. The manifold-pressure system takes no account of variations in fuel or atmospheric humidity, and the temperature-controlled devices involve some form of servo-motor. Control by explosion pressure promises effectiveness in a very simple device, and, when this development is available, higher power-outputs may be enjoyed without fear of the bad-fuel belt or of those operators who think that oil temperatures indicate engine heat, which factors at present are limiting the commercial ratings.

I realize that most of the remarks in this paper do not apply to engine designs giving low outputs, whether intentionally or not, and that such engines are the easiest to design and build. Small valve-areas, low compression and absence of supercharging greatly reduce overheating difficulties. Reliability is easily attained in such engines, which will also stand much abuse. All airplane operators and designers are rightly insisting upon improved reliability, and those who will sacrifice performance to this essential will use low-output engines as the cheapest way. The majority, however, in-

sist upon more speed and payload, looking to the engine designer to give them more power with less weight.

In my experience almost every new airplane design involves a demand for more power immediately following the first weight check or test flight. I believe that this competition cannot be met by engines of low output. Increased outputs require increased supercharging, which, in engines having the fuel present during compression, depends upon better cooling and fuels.

The reason for the vogue of the directly air-cooled engine is the weight and plumbing saved by the radial type and by the elimination of the separate radiator. Recent developments in cowling have remedied the head-resistance handicap of the radial type. Progress in air-cooled cylinder-head design has raised the limit to power output that is imposed by internal head-temperatures, which now compare favorably with those of the hot-points in liquid-cooled combustion-chambers.

THE DISCUSSION

CHAIRMAN ARTHUR NUTT[2]:—There has been some discussion pro and con about the value of the spark-plug cooler. Even if it did not lower the temperature, as it actually does, it is a very good radio-shielding device, which is necessary in all engines whether transport or military.

A fact that has been found out in the development of engines is that the same power or higher power can be obtained by means of higher compression-ratios and lower supercharger-blower ratios, and the valves cool better and the piston-rings do not stick.

Desire Commercial Fuel of 80-Octane Rating

D. P. BARNARD, 4TH[3]:—What results might be expected from some increase in the knock rating of the fuel? For example, at present it is generally thought that 75-octane-number fuel will take care of most of the standard-compression engines that are being used. That, I believe, includes engines which are not boosted on the ground but run at compression ratios that permit around 140-lb. brake mean effective pressure at the maximum. If we were to go to 80-octane number, I assume that we could get considerably higher brake mean effective pressures in general practice, and if we were to go to the Army specification of 87-octane number for this antiknock rating we could get still more.

Has Mr. Chilton any particular values in mind which would help us to orient ourselves as to what can be expected in general service from these octane numbers or even some higher knock-rating fuel?

ROLAND CHILTON:—We have prepared curves that show the relation between knock rating of the fuel and the maximum permissible break mean effective pressure at some specified limiting head-temperature. We have also been making a rather determined effort to get the oil people together to see if we could not agree upon 80-octane-number fuel and have it developed for commercial use. If that were widely distributed today we could rate the so-called 300-hp. J-6 engine at 400 hp. without changing anything but the blower ratio. The engines have been tested on this 80-octane-number fuel and it has been found satisfactory.

For commercial purposes 80-octane number is about as high as we can expect to go now. For special use, such as for racing, there is, of course, no limit to how high we can go. If the oil companies could give us a 200-octane number, if there were such a thing, we would be delighted and could then show some really good power-output. It is most unfortunate that alcohol is not a good fuel because, if that could be burned in an automotive engine, the compression ratio might be 10:1 and the engine would show a corresponding increase in power and would not be loaded, on the temperature basis, any worse than it is now.

High Piston-Temperatures Punish Lubricating Oil Severely

MR. BARNARD:—The thought I had in mind relates more to the condition common to automobile engines, for which we find it is necessary to supply a fuel which gives a very appreciable margin of safety between the compression ratio which can be carried in an engine on a test run and the ratio that can be used in engines for everybody to use.

I have in mind one J-6, 300-hp. engine that is punishing the lubricating oil quite seriously, apparently because of rather hot pistons. I had hoped to hear that 80-octane-number fuel, for example, would result in lower piston-temperature so that the lubricating oil would not be punished so severely, although it would permit raising the supercharger ratio. I hoped that a fuel of 80-octane number or still higher would not only raise the immediate specific power-output but also ease up on some of the stresses in the parts of the engine.

MR. CHILTON:—Undoubtedly it would do so. When we boost the over-all compression-ratio with the supercharger alone, the piston temperatures become higher than we like. It is much better to get the boost by increasing the piston compression-ratio somewhat and raising the supercharger pressure a moderate amount rather than doing it all in the supercharger.

The octane rating of a fuel undoubtedly has a great effect on the piston temperatures. I suspect that the oil tests we have been hearing about were in what we call the *D* head, which has since been superseded by the *E* head. The latter improves the cylinder-head temperatures, I would say, about 100 deg. That will make a difference between detonation and no detonation. When detonation occurs, regardless of which particular hot spot starts it, the temperature of the whole cylinder increases and is reflected in the piston. As Mr. Barnard said, that is severe on the lubricating oil. If comparisons could be made on oil tests as between the old and new heads, they would be very interesting.

It is essential that we have the temperature in mind continuously if we are to get a big margin of safety at the maximum rating. That is why I am so insistent about cylinder-head thermocouples.

Best Location for Thermocouple

HAROLD NUTT[4]:—What location would you select for a thermocouple in the cylinder-head?

MR. CHILTON:—We put numerous thermocouples on

[2] M.S.A.E.—Vice-president of engineering, Wright Aeronautical Corp., Buffalo.

[3] M.S.A.E.—Research engineer, Standard Oil Co. (Indiana), Whiting, Ind.

[4] M.S.A.E.—Director of engineering, Borg & Beck Co., Chicago.

the first engine of a type that is to go into an airplane with a specific set-up and find out which cylinder in that particular installation tends to run the hottest, and thereafter we use the thermocouple on that one. The instrument is put out all complete by the General Electric Co. It has a special spark-plug washer, and all that is necessary is to take out the spark-plug, insert the washer, put the instrument in the cabin and attach two wires to it. No battery is connected with it.

CHAIRMAN ARTHUR NUTT:—That goes on the rear spark-plug where the greatest heat is usually found.

HAROLD NUTT:—Have any corrosion effects been noticed with the use of a spark-plug cooler, or is ventilation provided to prevent that?

MR. CHILTON:—The coolers are quite unventilated; we try to make them water-tight. The standard test is to turn the stream from a 2-in. hose on the engine. The shielding that we now have stands that test very well and we have had no corrosion troubles with it.

Cylinder-Head Design for Effective Cooling

G. C. BROWN[5]:—Has any work been done on forging the cylinder-heads and machining the fins? I understand that one company is making such cylinder-heads and that they require about 150 machine operations. Sometime ago we made a block forging for an experimental Diesel-engine cylinder-head and the fins were machined. The report that I got from the test was that it worked very well. That would be one method of getting the fins very close together but the cost would be very high. Do you know of any work that has been done by that method in this Country?

MR. CHILTON:—We tried to lay out the heads with the valve disposition and the shape that we would like to have and then find out how to mill them. I am optimistic about the amount of machining that one ought to force the production department to do but decided we would better laugh off the idea.

MR. BROWN:—A short time ago I saw a cylinder-head for one of the relatively low-output engines which was giving some difficulty with valve seats and valves. The engine could not be run 50 hr. without the valves burning. In going over the job, the head of which was very poorly designed, the air-flow at the rear of the exhaust port was found to be very bad. An aluminum exhaust stack having a baffle that extended to the rear so as to divert air to the hot spot was made, and the head temperatures immediately dropped 100 deg. fahr. This, together with widening the valve seat from 3/64 to about 1/8 in. cured the trouble, so the builders have been able to fly the engine for several hundred hours without exhaust-valve difficulties. The location of the baffle apparently has a great deal to do with its effect. Impact of the air on the fins seems to be a point that has been overlooked. Most persons think that the air, being elastic, will do all sorts of tricks, but it will not; unless it is led where it is to go, you can always expect hot spots around the cylinder-head, with resulting troubles.

I believe that the great difference between the temperatures at the intake port and exhaust port has not been fully realized. Recently I saw a chart of temperatures on an engine in which there was more than 250 deg. difference in temperatures between the two ports at similar spots and locations. I often see cylinder-heads that have as many fins on the intake port as on the exhaust, whereas they should be only on the exhaust port, to balance the head temperature as much as possible.

Good Air-Flow Seems a Baffling Problem

MR. CHILTON:—That is in line with our experience. The widening of the valve seats and the provision for good air-flow around the back of the cylinder reduces the temperatures. We also make every effort to get the exhaust-valve-guide boss down as close to the valve head as possible so as to have the absolute minimum exposure of valve stem to the hot gases.

I can confirm all that you said about baffles. In one 12-cylinder V-type air-cooled engine, the air-flow is stopped at the back of the engine by a bulkhead. It was supposed to pass out equally through the spaces between the cylinders, which are perfectly symmetrical, but we were amazed when we found how the air was going. We spent some months designing baffles to make the air behave and, if anyone had not had experience, he would be astonished to see the kind of baffle that had to be made to get an approximately equal distribution of air.

In the spinner cowl mentioned in the paper, the air-flow was restricted by baffles to the finned periphery of the engine only, all the spaces between the cylinders being completely blanked out. The total air-flow area past the engine is thus merely the area of the finned profile, and the areas of the entrance hole in front of the spinner and of the exit slot are kept down to this small figure, which proportions work very well on test.

MR. BROWN:—One cylinder-head I saw had a very interesting provision for cooling the exhaust-valve stem. The rocker-box was raised slightly and an air passage was provided between the bottom of the rocker-box and the top of the exhaust port, permitting air-flow around the boss of the exhaust-valve-stem guide. After running 250 hr., the exhaust valve appeared to be as good as it was after 5 hr. of operation. Apparently, the cooling there was unusually good. The engine was not an extremely high-output engine, and I do not know what would have been the result if it had been stepped up to get more horsepower out of it. The idea looked good, although it added some weight to the head and the valve stem.

MR. CHILTON:—If we are to keep the diameter of the engine down, the gap between the top of the port and the bottom of the slot will be narrow and the total amount of air that can get down there will be relatively small. The heat conductivity of aluminum is so high that it may be better to close up the slot with metal and put more fins on the outside, where they will enjoy a good air-flow.

Short Pistons Prevent Adequate Ring Combination

H. M. BRAMBERRY[6]:—Piston temperatures have a good deal to do with piston-rings sticking, on the short types of piston where an inadequate number of rings is used. It is impractical to reduce the piston head temperature without increasing the heat-flow across the rings to the cylinder proper. Aircraft-engine pistons are so short that an adequate number of rings cannot be used to dissipate sufficient heat from the head. Virtually all of the heat that leaves the piston head will pass through the rings if enough rings are there to convey it. More rings will better seal the combustion-chamber and establish a path for heat-flow across the head to the cylinder wall that will substantially reduce the

[5] M.S.A.E.—Sales engineer, aircraft division, Bohn Aluminum & Brass Corp., Detroit.

[6] M.S.A.E.—Engineer, Perfect Circle Co., Hagerstown, Ind.

piston-head temperature and be a real improvement. I think that considerable improvement can be accomplished if some consideration is given to the subject along this line.

MR. CHILTON:—There is no question about that. We sacrifice a great deal to get the engine small in diameter. The airplane has to be pulled through the air, so we want a streamlined body, and we engine designers have to do something toward that.

In a J-6 engine the clearance between the piston skirts and the counterweights is 1/32 in., and we resort to every other expedient we know in order to get the over-all diameter down. If we could use a longer piston to stop the tilting and more rings to give better contact, I believe that we should be much better off. Without doubt something of that kind must be done soon in engines of these increased power-outputs.

The most hopeful thing is the high-compression engine, if fuels are improved. More of the heat will go into useful work and less will flow to the piston and the cylinder-walls.

An oil man told me a few days ago that the hydrogenated oils would eliminate piston-ring sticking because they would not carbonize. If that is so, it is going to be very delightful. We must keep piston temperatures at such a point now that we do not have stuck rings.

MR. BRAMBERRY:—The rings will continue to stick even though the piston temperatures are lowered, because, with the conventional rings, after the oil is displaced from the lower edges of the compression rings under pressure, it is impossible to get this oil back behind the rings as long as the throttle is open. That is the major difficulty. No matter how much oil is used, it does not pass around the backs of the rings under load. Rings are available that will trap the oil and lubricate the plain surfaces under pressure.

MR. CHILTON:—We have been trying to make up our minds whether it is better to get less oil or more oil back of the rings. I am inclined to believe that we need more. In the case of vent holes in the back of the groove, I imagine that the ring enjoys plenty of oil. Usually the oil-scraper ring is the last part to stick, probably because it is the one at the bottom of the piston.

Poor Mixture-Distribution Causes Most Trouble

MR. BARNARD:—We have had some experiences during the last year that indicate piston trouble due primarily to poor distribution of the mixture and not to detonation. The number of airplane engines which have intake systems that would be regarded, from the automobile-engine designer's viewpoint, as rather antediluvian is surprising to me. The air velocities are quite low and everything possible seems to have been done to induce any nonvolatized portion of the fuel to trickle along the outside passages and find its way to any one or two cylinders of the seven or nine it chooses. The temperatures in those intake passages will run considerably below atmospheric, and very often, even in spite of the so-called hot-spot, very little heat-transfer capacity of the airstream is noted. Temperatures even beyond the hot-spots are 40 or 50 deg. below atmospheric, which is a great deal on a cold day. If the increasing of supercharging ratios is very easy, would there be some hope of getting better over-all distribution, especially in cold weather, but putting a few corners and the like in the induction system to get mechanical atomization and better distribution, compensating for the drop in pressure by a little higher supercharger ratio?

I recognize that, if we do not have blowers, it is necessary to have smooth contours to get good volumetric efficiency; but if we have blowers which are not working to their best output merely because the fuel will not stand a higher compression-ratio, it might be well to use some of that extra capacity to atomize the fuel and get better distribution.

MR. CHILTON:—As soon as we supercharge we take care of that. A temperature of 100 deg. in the intake manifold is quite common, because of the temperature rise in the supercharger. The trouble experienced at substantial ground-boost is not distribution trouble at all; when we get above idle we are more or less all right.

I think that even on the commercial J-6 engine, where the pressure in the manifold is only 2 in. of mercury, you will never find sub-atmospheric manifold temperature, and that these temperatures are well above atmospheric at full throttle. We find that a properly designed centrifugal supercharger having symmetrical radial inlet pipes will distribute the fuel if there are no obstructions in the diffuser. However, I have never seen a supercharged aircraft engine that would idle consistently well. That is one of the things on which we are working.

I do not think that it is necessary to put any corners in the manifold to secure good distribution. It certainly is not necessary to do anything on a ground-boosted engine to increase the manifold gas-temperatures; as a matter of fact, they are too high and, as the next step, we have to bring them down before we can go to a very greatly increased supercharger pressure.

Safe and Dangerous Temperature Ranges

H. K. CUMMINGS[7]:—The Bureau of Standards sees many designs of air-cooled engines from time to time, although our testing of engines is very rudimentary. We are not permitted, and do not have the time, to examine into the engines, but only put them through a rather limited test. We also have considerable to do with engines that are not developing anything like the brake mean effective pressures that can be got from aircraft engines. Nevertheless, we are much interested in the temperatures that develop in air-cooled engines on the test stand and in the differences between temperatures in cylinder-heads and cylinder-barrels and the effect of conditions on those temperatures. We hope that in time we shall be in a position to look into the way those conditions vary.

We are entirely in accord with the analysis of what temperature shows; that increased power-output, inadequate cooling, unsuitable fuel, leaning of the mixture, charge temperature and humidity, all make themselves evident by a rise in cylinder temperature.

I should be glad to hear whether, in the author's opinion, there is any range of head temperature that is, perhaps, designated as a satisfactory range and any range that is definitely a danger range. Or must we determine in all cases that, under entirely satisfactory conditions, the temperature at some point is a given figure and that a marked departure from that temperature indicates danger? That is, is it possible, in a rough way, to establish satisfactory temperature-ranges

(*Concluded on page* 227)

[7] S.M.S.A.E.—Chief, automotive powerplants section, Bureau of Standards, City of Washington.

Coordination *of* Engine *and* Carbureter

By O. H. Ensign[1]

Southern California Section Paper

FUNDAMENTAL principles of the various details of carbureter design are treated in the first part of this paper. Elementary forms are described and reasons are given for such modifications as have been found necessary. The accelerating pump and economizer in particular are treated as to their various forms and functions. Attention is given to the interrelation between carbureter and engine and especially to problems of manifolding and distribution.

Fuel economy is stressed as a real need for present engines and a potentially greater need for the future. A series of fuel-economy curves is given, showing results obtained with and without an economizer, with gasoline and kerosene in tractor engines, and with various gear ratios in a passenger-car. Emphasis is give to the influence of gear ratio on economy; and the ideal transmission system is said to be one that would make the engine go slower when the power requirement is low, so that it might be working under a high torque load at all times.

IMPROVEMENT of the product along various lines has been the constant aim of the automotive industry. It is my intention to review this development insofar as it pertains to the combination of engine and carbureter, to show what has been accomplished.

Ideal engine performance includes maximum power and flexibility with the minimum fuel consumption under all conditions of operation. Maximum power is obtained when the depression in manifold and carbureter are the minimum that can be used with a given engine, while maintaining flexibility. The factors that control this are the size and design of the manifold, the heat control of the manifold and circulating water, and a carbureter design that can take advantage of the favorable points of the engine design.

A manifold may have a large cross-section, with which a carbureter of low depression can be used, and obtain a desirable increase in power at maximum rated engine-speed during warm weather, but at average temperature it will cause poor flexibility and fuel economy even with well-worked-out temperature-control of the circulating water and manifold. This condition makes it necessary to compromise in the combination of carbureter, engine and manifold, as is not unusual in good engineering practice along any line.

Our idea of flexibility is a work-out of the carburetion of an engine such that, after the engine has been warmed up and while the car or truck is running at any speed above 2 m.p.h. in any gear, the operator can throw the throttle wide open or part-way open quickly or slowly without finding any so-called flat spot and the vehicle will accelerate as it should, if the correct gear has been engaged for the conditions of grade and load. Performance requirements for a tractor are the same and, in addition, the maximum load must be picked up from a standstill at any time by engaging the clutch with any selected gear.

It may generally be assumed that a carbureter can be fitted to any engine, regardless of the design of the engine and the manifold, which will produce flexibility such as has been indicated in the foregoing, but the design of the engine and manifold must be well worked out to make the maximum economy possible. Many engines exist that show excellent results, and development during the last 10 years indicates that great progress has been made and still better results can be expected.

Economy is the demand of the present and will be demanded still more strongly in the future. Natural resources that have been stored in the crust of the earth in past ages are being consumed, and these resources are not being added to. The time may not be far distant when we shall be compelled to economize both because of the higher price of fuel and because the earning power of the automobile may fall owing to the reaction after the last 10 years of unusual prosperity.

I shall treat the subject of carburetion and its relation to powerplant operation as though I were addressing those who are unacquainted with the fundamental principles and detailed technical disclosures of the art, for the benefit of those who are interested in operating problems but have not had special experience in testing engines and carbureters.

Early Carbureter Development Traced

Carbureters may be divided into classes according to the design and construction methods used in an effort to produce a suitable mixture under any condition of engine operation.

In the early days, a mixture was produced by causing part of the intake air to flow under the surface of the fuel in the tank to carry a portion of the fractions of the fuel that would vaporize into the primary air-stream. With the fuels then available, the fraction that would vaporize was a large percentage. The mixture was modified to make it combustible by adding air by manual control. A modification of this method utilized a wick dipping into the gasoline, part of the air flowing over this wick to pick up the fuel. Both of these methods were subject to great risk from fire and explosion; and they were used only during early stages of engine development, when the gasoline was very volatile.

Next in order of development was the drawing of fuel into the air-stream by utilizing the drop of pressure in the air passing through a constricted opening,

[1] M.S.A.E.—President and chief engineer, Ensign Carburetor Co., Ltd., Huntington Park, Calif.

the fuel being atomized as it entered the air-stream. It was immediately discovered that such a device would not meter correctly, because the expansion of vaporized fuel in the restriction tended to cause the mixture to grow richer with increasing air velocity.

One of the first ways of correcting this condition was by the use of an auxiliary air-valve which allowed a controlled amount of air to flow into the suction passage and mingle with the very rich mixture of the initial air into which the fuel was fed. Reasonably good improvement was obtained in this way by careful development of spring control for the air valve and other devices. The good performance that could be obtained by this method contributed largely to the rapid early development of engines, and modified forms of the air-valve type of carbureter still give excellent service. Other methods of obtaining a reasonably good mixture throughout the operating range that were applied to the so-called venturi-tube type of carbureter include compensating jets; air bleeds into the fuel stream, applied in different ways; and combinations of the different methods. A very good operating curve of fuel could be secured by these methods if enough care was used.

Accelerating Fuel Needed with Heavy Gasoline

Methods such as have been described did fairly well until the use of gasoline increased to such an extent that it was necessary for the refiners to utilize the heavier natural fractions and to introduce cracking. No accelerating fuel was required because the gasoline was so volatile that it moved into the air-stream more easily than the present fuel and the air-valve carbureters tended to start some fuel ahead of the main air-stream. Furthermore, virtually all of the gasoline was vaporized easily, so that it readily passed on into the engine cylinders with good distribution, as would a true gas.

Gasoline marketed up to 1910 would boil perfectly dry at a temperature little higher than 300 deg. fahr. The demand for automotive fuel increased very rapidly soon after the beginning of the World War in 1914, and the increase in demand has continued since. Now it is not uncommon to find gasoline in which considerably less than 50 per cent of the fractions will boil off at a temperature below 300 deg. and some of the fractions require 450 deg.

If a manifold is kept hot enough to vaporize completely such fuel as this and obtain flexibility, it is easy to see that the volumetric capacity of the engine, and the resulting power output, would be very much reduced. Another difficulty caused by high manifold heat would be the tendency for the manifold to become dry during the high depression resulting from closed-throttle operation, so that virtually all of the fuel fed for a short time after the throttle is opened to pick up the load would be required to line the walls of the manifold before enough fuel could reach the cylinders to produce a combustible mixture. Therefore heating alone would not result in good flexibility, even if a very rich mixture were used throughout the working range.

To overcome this difficulty, it became necessary to deliver a momentary excess of fuel immediately upon opening the throttle. Some of the reasons for the need of this accelerating fuel, which are not universally understood, are:

(1) When the engine is warm and the throttle is closed for idling or coasting, the depression at the carbureter is such that the resulting manifold pressure is less than one-half atmospheric pressure. This partial vacuum quickly evaporates a large proportion of the liquid fuel that is in transit through the manifold and makes the walls of the manifold virtually dry.

(2) The fuel responds less quickly than does the air to a change in suction, this condition being worse with the heavier fuels. To illustrate, if a quick opening of the throttle imposes on the fuel jet a depression measured by a 25-in. column of water, the air will immediately move with a velocity of 330 ft. per sec., while the fuel will have a velocity of only about 12 ft. per sec. Furthermore, the acceleration of the fuel is not so rapid, because of the length and shape of the fuel passage to the jet.

(3) Time is required for the vaporization of the heavier fractions of the fuel, therefore it is necessary to deliver accelerating fuel in excess of that supplied from the main fuel-jet to the hot-spot, so that the medium and light fractions of the fuel which can be evaporated quickly will help to fill the dry manifold with vapor and fuel will be supplied to wet the inside of the manifold.

(4) Enough excess fuel must be supplied momentarily so that the fractions that do vaporize readily may flow readily or instantly with the air to maintain a working mixture in the cylinders.

The last two reasons are similar to the reason for choking the carbureter in starting a cold engine; it would be impossible to start an engine except in hot weather if there were no light or easily vaporized fractions in the gasoline, boiling at say 100 to 130 deg. fahr. The choke causes sufficient fuel to be drawn in so that the cylinders are fed enough of the lighter fractions to operate the engine until heat is developed to make the heavier fractions available.

Even after the powerplant is warm, it is necessary to supply small measured injections of fuel in addition to the normal flow through the jet to be released immediately upon the opening of the throttle. This has been accomplished in many different ways. While the first means was a plunger which momentarily raised the level of the fuel in the float-chamber, another method was by storing fuel during idling in an enlargement of the passage leading from the float-chamber to the fuel nozzle, thus making it more readily available than fuel that must be drawn suddenly from the float-chamber. Another method was to elevate the fuel from the fuel chamber during idling and hold it above the jet level by means of the manifold depression, to be delivered into the air-stream by gravity and in some cases by gravity and suction when the throttle is opened. Still another method is to use a force pump of some sort operated by the movement of the throttle shaft. All of these methods are in use today with marked success.

However, all the foregoing methods have the disadvantage that a certain amount of excess fuel is delivered every time the throttle is opened, whether or not it is needed, and the amount of excess fuel is difficult to control. No doubt many of you have followed vehicles from which you have noticed black smoke to be emitted at each acceleration. This usually indicates that something is out of order, although there is sure to be some excess fuel delivered at times.

Economizer Corrects Mid-Range Richness

Another important line of carbureter development is the so-called economizer. The application of compensation to overcome the natural tendency of the mixture

to become over rich at higher velocity and the provision at the same time for a suitable supply of fuel for acceleration and smooth power at open throttle cause a mixture at part throttle that is altogether too rich for economy. This is because the mixture at extremely low speeds may need to be quite rich to have the correct mixture for maximum power over the entire speed-range with wide-open throttle. An engine that is intended to operate wide open down to 400 or 300 r.p.m. should be rich in that range. This is especially true for trucks and tractors, and does no harm in automobiles because the engine will often be pulled down to this speed in starting a heavy load, and no accelerating fuel can be provided to make sure of continued operation to pick up the load from that low speed. Such a rich range will not affect the full-power economy, and is used only momentarily.

Unfortunately, however, this rich low-speed wide-open mixture is generally reflected in the fuel consumption in the controlled-speed part-throttle range, therefore some method of thinning the part-throttle mixture should be applied that does not affect the mixture at idling speed or when the throttle approaches the wide-open position.

It has been demonstrated that, under the condition of high manifold depression that exists when the power and speed are controlled by the throttle, an engine will operate smoothly with a quite lean mixture, because the high manifold depression vaporizes the fuel more completely. A mixture considerably leaner than the proportions required for perfect chemical combination can be burned in some powerplants. This condition makes possible the use of an economizer device that will have little or no effect upon the power range at wide-open throttle.

Forms Which the Economizer Takes

Many different arrangements are utilized to secure the economizer effect. It can be done by an attachment or arrangement of parts or bleeds that can be cut in and adjusted after the wide-open curve is worked out, or it can be included as a part of the general specifications. However it is brought about, adequate operation of an economizer is of the utmost importance in its effect upon the all-round working economy, because full power seldom is required for any extended time. The high vacuum normally existing in the manifold causes the fuel to be thoroughly vaporized and well distributed, resulting in almost perfect combustion.

Economy of operation in the part-throttle range can readily be tested by the following procedure: retard the spark fully, so that the throttle can be opened fairly wide without excessive speed; open the throttle with the engine accelerating idle to various speeds, and open the starting choke slowly after each speed has become constant. If the engine is being operated at best economy under throttle-control conditions, a definite but not large increase in speed should be observed at some degree of closing of the choke.

When an economizer arrangement is operating at its best, the accelerating device should be adjusted so that the accelerating well can be kept full at light-load throttle-openings up to a relatively high speed and discharged only when actual acceleration is needed. It should be ready with some excess fuel at all speeds up to one-half of full speed. If it is not, the operator is sure to enrich the high-speed mixture for improved performance, thereby defeating the result in economy that is sought.

From the foregoing it appears that the opportunity exists for the application of a tremendous amount of ingenuity and research to the problem of carburetion. As an indication of the efforts that have already been made, about 18,000 patents or carbureters have been issued in the United States. Many of these are entirely useless, and many other fruitless efforts contain some kernel of thought that is needed to make a complete success of a new effort. Meantime, extensive improvements have been made in the design of engines and manifolds. A study of the different powerplants and engineering papers indicates the marked difference of opinion as to the best solution for the extremely complex problem of securing economy from the combination of carbureter and an engine, with a universal tendency toward a better understanding of the problem. The future should give us great improvement over present devices.

Manifolds and Distribution

For study of the general subject of manifolds and distribution, I recommend a careful reading of a paper on the subject by Alex Taub[2], together with the discussion on it. It is gratifying to find that many of the ideas expressed therein agree with those in a paper of mine[3] read about 10 years ago. Mr. Taub's paper indicates correct methods for testing and judging distribution.

Important points to be kept in mind are that a path for the mixture has been developed experimentally to a size such that the gas velocity will be as favorable as possible to the operation of the engine under all conditions, at the expense of only a slight reduction in power at maximum speed. When the valve pockets are siamesed, the back wall must be flat and the entrance to the port should have abrupt corners. The inside corners of all elbows should be sharp; the outside turn in some cases may be rounded and in other cases an improvement may be found by making it nearly square or with a slight recess. The riser should join the horizontal run with a sharp, square corner.

The length of the riser is an open question. Unquestionably the condensed fuel always flows up the wall of the riser with a spiral movement, and the heavy stream of fuel will strike the tee at different point around its junction according to its velocity and the length of the riser. Most of the evidence accumulated indicates that a riser of short or medium length is the best, with the hot-spot surrounding the riser and the tee. The area of the hot-spot and the general heat of the manifold are subjects for much study. Our own experience indicates that it should be made as small and as hot as possible and that the rest of the inlet manifold should be kept as far away from the exhaust manifold as possible, the effect being that a portion of the fuel will burst into vapor or fog on striking the hot-spot and that more of the fuel will be turned into fog as it moves along the colder part of the manifold. This fog-like mixture will float on the air with little condensation and supply the cylinders with a readily inflammable mixture which will assist in the complete combustion of the whole charge. I have used this method many times, and it has given good operating results even with kerosene.

With the present fuels, a relatively large proportion of the heavy fractions reaches the engine valves either in

[2] See S.A.E. JOURNAL, April, 1930, p. 454.
[3] See THE JOURNAL, July, 1920, p. 19.

the form of droplets supported by the turbulent air-stream or as a small stream of liquid fuel flowing along the manifold wall, and the most difficult part of the problem is to make sure that this liquid-stream portion is delivered equally to all cylinders. To this end, valves in siamesed pockets should be no larger than is necessary to obtain the maximum power. When two unnecessarily large valves in the same pocket open successively, the first one to open will draw the major portion of the liquid-stream fuel from the pocket and the nearby manifold, causing the mixture in that cylinder to be rich and that in the succeeding cylinder to be lean.

Curves of Fuel Consumption Shown

Curves of engine performance can be used to illustrate some of the foregoing points. Fig. 1 shows the fuel consumption of a four-cylinder tractor engine using gasoline. The part-throttle curve represents the consumption with the engine operating at a constant speed of 850 r.p.m. under governor control, while the open-throttle curve represents conditions when the speed is controlled by the load. Numerals on the latter curve and the open-throttle curves in succeeding figures indicate the speed at various points. The open-throttle curve lies between 0.60 and 0.62 lb. per b.hp-hr. throughout, and lies close to 0.60 at a little below full speed. The part-throttle curve remains close to the open-throttle curve down to four-fifths of full load, is less than 0.80 lb. per b.hp at one-half load and is 1.23 lb. at one-quarter load. This curve represents an engine that operates well in the field, but I should prefer to have the low-speed end of the open-throttle curve considerably richer.

Another four-cylinder tractor engine operating on gasoline is represented by the curves in Fig. 2. This wide-open curve shows a gradual increase in fuel consumption as the speed drops, while the part-throttle curve indicates lower fuel consumption than the wide-open curve between full load and half load, going as low as 0.64 lb. per b.hp. The fuel consumption is only 0.78 lb. per b.hp. under part throttle at one-half load and 1.4 lb. at one-quarter load, indicating a very satisfactory application of the economizer in view of the moderately high consumption of fuel at low speed and open throttle.

The performance on kerosene of the same engine that is referred to in Fig. 2 is shown in Fig. 3, the only change in the engine being that the valve controlling the heat at the inlet manifold was closed when using gasoline and was suitably adjusted for kerosene, with a slight change in the carbureter adjustment. The maximum power developed with kerosene was 32.5 hp., against 35.5 hp. with gasoline. This is a remarkably fine performance with kerosene, the fuel consumption being somewhat lower than with gasoline. I should

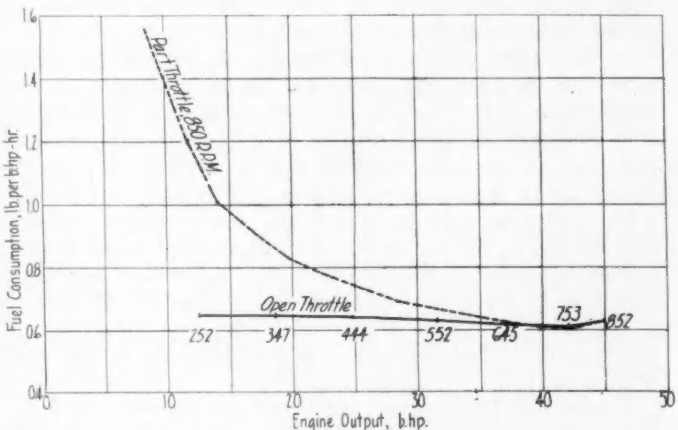

Fig. 1

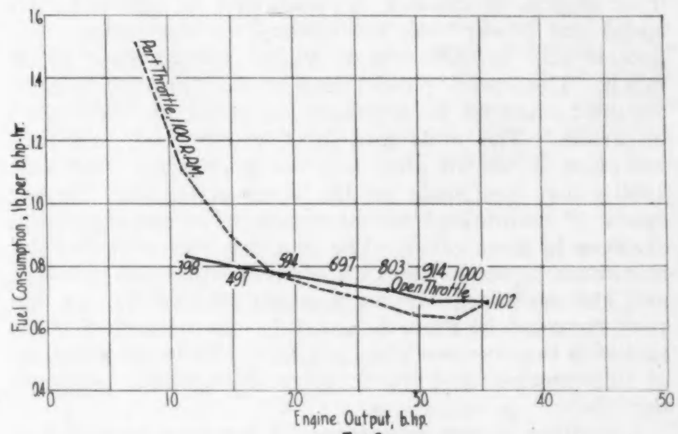

Fig. 2

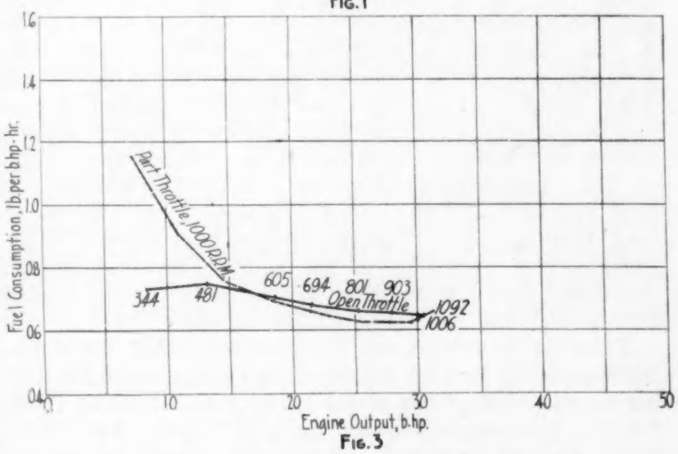

Fig. 3

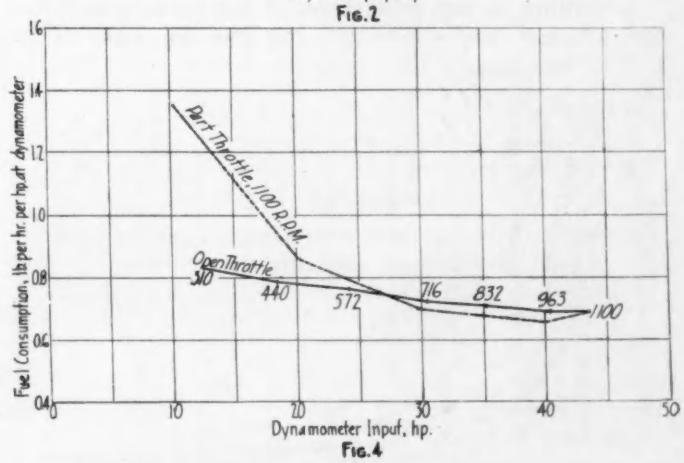

Fig. 4

Fuel-Consumption Curves of Four-Cylinder Tractor Engines

Figures on the Open-Throttle Curves Indicate the Engine Speed in Revolutions per Minute.

Fig. 1—An Engine Showing Nearly Constant Fuel Consumption at Full Throttle at Various Speeds

Fig. 2—An Engine Having Full-Throttle Consumption Decreasing at the Higher Powers

Fig. 3—Performance Obtained with Gasoline in the Engine of Fig. 2

Fig. 4—Curves from Tractor Engine Belted to Dynamometer

have preferred to see the low-speed end of the open-throttle curve a little higher, in a straight line with the middle portion of the curve.

Another four-cylinder tractor engine using kerosene is represented in Fig. 4. The horsepower readings in this case were taken from a belt-driven dynamometer and the speed readings refer to the crankshaft speed. The fuel consumption is referred to the net power at the dynamometer. In spite of gear and belt losses the fuel consumption is quite satisfactory. The part-throttle curve remains below the open-throttle curve nearly down to half-load. The consumption at one-fourth load is only 1.3 lb. per b.hp-hr. at the dynamometer. This powerplant picks up the load and accelerates satisfactorily in the field, and indicates the fine use of the economizer.

All four of the foregoing examples were worked out by the fish-hook method for both wide-open and part-throttle curves, and the carbureter was developed to give those results automatically. They show that there is no difficulty in producing highly economical records on the part-throttle curve if the speed range is relatively low. When a high range of speed is required, the matter is not so simple.

Securing Economy in Passenger-Cars

The curves in Fig. 5 represent the performance of a production engine for medium-weight passenger-cars. This engine is capable of operating at much higher speed and power than are covered in the curves, that extend only to 2000 r.p.m. which is equivalent to 40 m.p.h. The speed is controlled by the throttle, to meet assumed changes of resistance imposed by head wind or grade. The wide-open-throttle curve of fuel consumption is shown also, and the curves for 1500 and 1000 r.p.m. are made on the assumption that the car speed is maintained at 40 m.p.h. with corresponding changes in gear ratio. The mixture was adjusted for maximum power at 2000 r.p.m. with wide-open throttle, and the same adjustment was maintained during the runs recorded in Figs. 5, 6 and 8. The object of these curves is to show how the gear ratio affects the economy of the engine and carbureter, particularly at part throttle.

According to my experience, it can be assumed that the average medium-weight car can be kept at 40 m.p.h. on a level road with an expenditure of between 18 and 20 hp. if there is no head wind. Assuming 19 hp., Fig. 5 indicates a fuel consumption of 0.80 lb. per b.hp-hr. if the engine speed is 2000 r.p.m., 0.70 lb. at 1500 r.p.m. and 0.63 lb. at 1000 r.p.m. The fuel saving at the latter speed is 20 per cent.

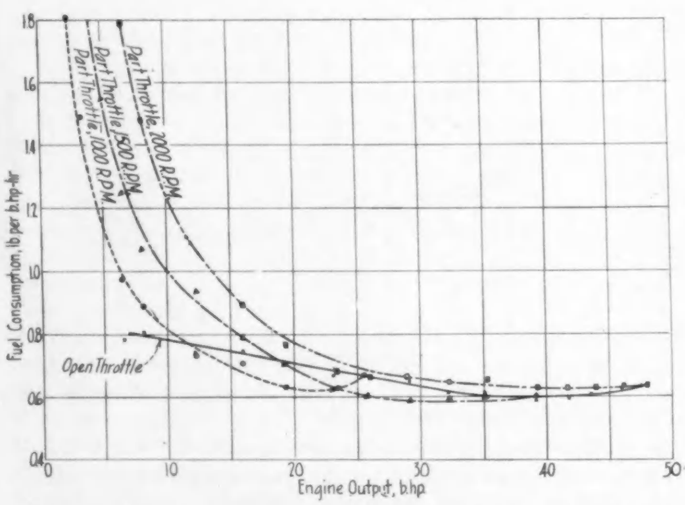

FIG. 5—FUEL-CONSUMPTION CURVES FOR AN AUTOMOBILE ENGINE AT VARIOUS SPEEDS

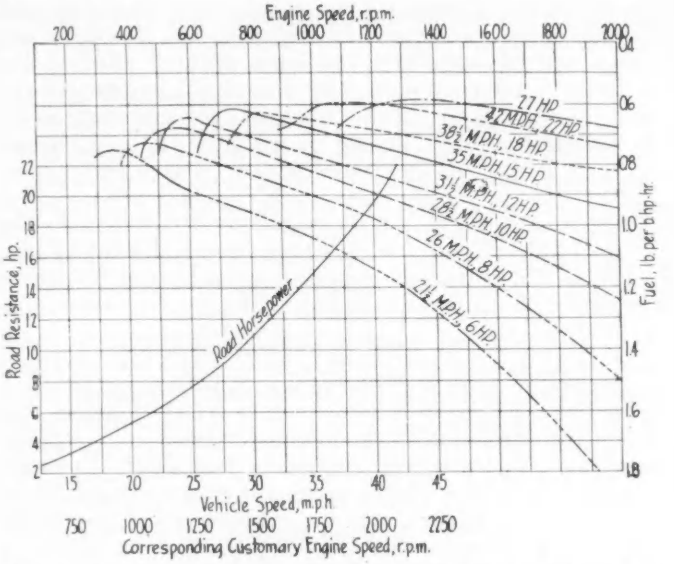

FIG. 6—FUEL-CONSUMPTION CURVES FROM ENGINE OF FIG. 5 AT VARIOUS OUTPUTS, ASSUMING VARIATIONS IN GEAR RATIO

If the same speed of 40 m.p.h. is maintained on a down grade such that only 15 hp. is needed, the fuel requirements for the respective engine speeds are 0.95, 0.82 and 0.70 lb. per b.hp-hr., indicating a saving of 25 per cent at the lower engine speed. With the load reduced to 10 hp., the respective fuel consumptions are 1.24, 1.00 and 0.82 lb. per b.hp., indicating a possible fuel saving of 35 per cent. Any reduction in the engine speed requires the throttle to be opened wider, resulting in better fuel economy because the engine is loaded with a larger percentage of its full load. A marked improvement in fuel consumption can be made in this way with a suitable economizer device.

A test run to demonstrate this condition better is recorded in Fig. 6, which was run with the same engine and carbureter setting as for the test recorded in Fig. 5. Included in this figure is a curve representing the assumed average horsepower required for a car of medium weight, at various road speeds. This test was run by starting with the various loads indicated on these curves at a speed determined by a corresponding point on the open-throttle curve on Fig. 5; the output was kept constant and the speed increased from this point, fuel readings being taken at frequent points. This gives a very fair idea of the relation between engine speed and fuel consumption on the one hand and engine horsepower and car speed on the other.

Take the lowest curve, for instance—that for 6 hp., corresponding to $21\frac{1}{2}$ m.p.h. The engine speed for this car speed ordinarily is about 1075 r.p.m., at which speed the fuel consumption would be 1.10 lb. per b.hp. If we could, by some method not yet discovered, secure the other desirable features of performance with a gear ratio that would make the engine run at 400 r.p.m. at this car speed, the fuel consumption would drop to 0.75 lb. per b.hp-hr. If the engine speed could be reduced even to only 800 r.p.m., the fuel consumption would drop to 0.95 lb.

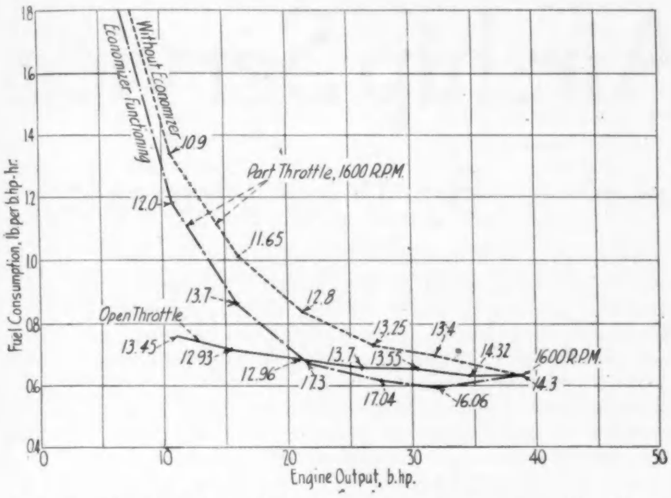

FIG. 7—IMPROVEMENT OBTAINED IN THE ENGINE OF FIG. 5 BY THE APPLICATION OF AN ECONOMIZER

Figures on the Curves Indicate Ratio of Air to Fuel

Similar conditions will be found from the study of the other curves. At 35 m.p.h., the engine in the ordinary car will be running at 1750 r.p.m., developing 15 hp. and consuming fuel at the rate of 0.89 lb. per b.hp. If the engine could be run at 800 r.p.m. at that car speed, the same work could be done with a fuel consumption of 0.62 lb. A similar condition obtains at 42 m.p.h., at which speed ordinarily the engine would be making a little more than 2000 r.p.m. and consuming 0.74 lb. per b.hp., while at 1000 r.p.m. the fuel consumption would be only 0.62 lb.

Gear Ratio Affects Economy

The foregoing is intended to call attention to the importance of selecting gear ratios suitable for the special conditions over routes where the routine of performance does not call for maximum power or extreme speed. It indicates the unfortunate characteristics of the present throttling type of engine, which serves the purpose so well in every other way. Many attempts have been made to correct this condition by automatic gear-shifting devices, but none of them so far has been considered marketable. Ideal performance would be secured by changing the gear ratio to control the load and speed instead of by throttling the engine. Somewhat the same effect can be secured by means of a friction drive, but that has been tried in actual operation and found to be sadly wanting.

Much attention has been given in the past to engine output at full load on the wide-open curve; more attention must be given to performance at part throttle. What can be accomplished by having an economizer built into the carbureter is illustrated by the two part-throttle curves in Fig. 7. The dotted upper curve indicates the consumption at 1600 r.p.m. and part throttle with virtually no economizer effect. A more advantageous adjustment of the economizer gave the results indicated by the dot-dash curve. This does not represent the limit of economy, which would be reached just short of the adjustment which would cause the engine to run unsteadily. This same engine operated on as little as 0.58 lb. per b.hp. at 1500 r.p.m., as recorded in Fig. 5.

The characteristics of the wide-open and part-throttle curves are further illustrated in Fig. 8, in which the air-flow is plotted against the horsepower with fuel consumption indicated by decimals at various points along the curves. From these curves it will be observed that the air consumption at 10 hp. and 425 r.p.m. with wide-open throttle is about 100 lb. per hr., with a fuel consumption of 0.773 lb. per b.hp-hr. At the same power output and 1600 r.p.m., air was used at the rate of 150 lb. per hr. and fuel at 1.14 lb. per b.hp-hr. The comparison is similar between other points on the curves, only that the points are much closer when the engine is loaded to a little more than one-half its maximum horsepower. This is evidence that a large portion of the power at part throttle is consumed by the engine internally, in pumping the air needed to do the work, and the fuel consumption is higher also because of the lower compression.

While the constant-volume automotive engine and carbureter have been improved in detailed design to make them more dependable and more powerful, they have stood still for years in the development of means for utilizing their possibilities in regard to fuel efficiency. A few isolated examples of designs involving special transmissions are the only exceptions.

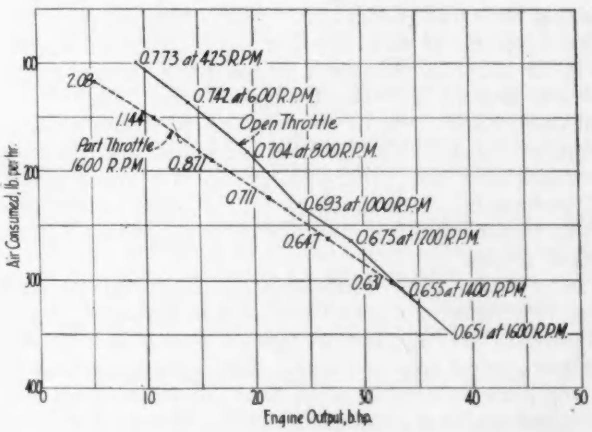

FIG. 8—AIR-CONSUMPTION VERSUS FUEL-CONSUMPTION CURVES FOR THE ENGINE OF FIG. 5

Decimals on the Curves Indicate the Fuel Consumption in Pounds per Brake Horsepower-Hour

Transoceanic Airship Service

19th National Aeronautic Meeting Paper

By J. C. Hunsaker[1]

PLANS and preliminary studies with a view to ultimate operation of a transatlantic airship service between the United States and Europe are described. Two American groups have organized to develop airship transportation across both the Atlantic and the Pacific. The Atlantic group proposes to develop some form of cooperation with a German group that would provide German airships and European terminals, while the American group would furnish American airships and terminals. Weekly sailings each way with two ships is contemplated at first, and later semi-weekly sailings with four ships.

The general program presupposes completion of an exhaustive study of conditions and possibilities before actual construction of the airships and terminals is begun, but the German group has already started building at Friedrichshafen a huge terminal dock and a giant new airship to replace the Graf Zeppelin. The dock is to be completed in 1931 and the ship in 1933.

The author reviews briefly the flying records of the Shenandoah, Los Angeles and Graf Zeppelin, pointing out the present safety of this form of transportation and the payload capacity on long flights. A revised design of the Akron, now nearing completion, for commercial service has been used as the basis for a study of transatlantic operation. Analysis of weather records for the past 20 years has shown that the best location of the American terminal is somewhere in the neighborhood of Baltimore, Washington, Richmond or Philadelphia; while in Europe a favorable location has been found near Frankfort, Germany. Mooring masts at New York City and Paris are contemplated.

An extensive research into weather conditions over the Atlantic has been conducted and investigators have worked out day-by-day crossings for a five-year period, determining the course that would have been followed and the time of crossing.

Estimates have also been made of probable passenger, mail and express patronage.

Such a service is held by the author to be noncompetitive with either steamship or airplane service.

TWO AMERICAN GROUPS, interested in securing for American interests a suitable part in what promises to constitute a new transportation industry, have organized to develop transatlantic and transpacific airship services. The initial purpose of the Atlantic group is to study the feasibility and economic merit of airship transport across the North Atlantic between Europe and the United States. The intent is to develop some form of cooperation in which a German group would provide German airships and European terminals and the American group American airships and terminals. The airships would offer to the public a joint service making free use of the terminal facilities of each group.

The general plan contemplates an ultimate service using two American and two German airships, giving a semi-weekly sailing; but, at first, a weekly sailing would be given, using two airships. Any frequency that does not compare favorably with that of steamships would not, it seems, be economically useful for the transportation of either the mails or passengers.

While the general program presupposes the completion of an exhaustive study before undertaking construction, the German group is already satisfied that airship transport is ripe for application and has proceeded with the construction at Friedrichshafen of a new airship terminal suitable for larger airships together with the new airship that is to replace the Graf Zeppelin. This terminal will be completed in 1931 and the airship in 1933.

In this connection it is important to understand that the German Zeppelin company is owned by trustees of the Zeppelin Endowment Fund and operates more like an American scientific or charitable foundation than as a commercial enterprise. The funds of the Zeppelin Endowment are required to be used for the development of aeronautics and are not restricted to German territory.

The American position is unique as regards helium gas, the only fireproof lifting gas for airships, of which the United States has a natural monopoly. The export restrictions on helium by the present law could give this Country a virtual control of international airship development.

Safety and Practicability Demonstrated

The American development of airships began with the Shenandoah, based on German practice; but evidently our weather can be more violent than that of Europe, and German factors of safety cannot safely be adopted here, as the Shenandoah was wrecked in a storm. However, as she was inflated with helium, no fire occurred and, although the ship broke in two in the air, most of the crew floated down to earth in safety. Consequently, the engineers could learn from the survivors just what happened.

In 1924 the United States Navy acquired the Los Angeles from Germany, and Dr. Eckener delivered her to Lakehurst, N. J., a non-stop flight that was the forerunner of 16 more flights of comparable extent to be made by this master navigator in his own ship, the Graf Zeppelin. The Los Angeles, which is seven years old, flew to Panama last winter to take part in the maneuvers of the American fleet and remained away from her base for 27 days in the open.

The German Graf Zeppelin was built as a commercial demonstration ship. With her Dr. Eckener has made 160 flights with passengers, among them 16 transcontinental and transoceanic flights, including a trip around the world. In two years the ship made 145,000

[1] M.S.A.E.—Vice-president, Goodyear-Zeppelin Corp., New York City.

miles in 2321 hr. of flight and carried 6772 passengers and 31,000 lb. of mail and express. In these two years of operation there has been no injury to either passengers or crew, and the income account has been very gratifying. Also, it is now clear that passengers do not hesitate to patronize an airship whose safety has been demonstrated.

As a technical experiment the Graf Zeppelin has shown, first, that airship operations are practicable in all climates from Arctic to tropical; second, that flights were started on schedule 96 per cent of the time; third, that flights, once started, were continued regardless of weather; fourth, that in a mechanical breakdown at sea, when four out of five engines were disabled, and in another case of serious structural damage, the airship could proceed safely to the nearest port just as a steamship might do in similar circumstances.

The Naval airship, the Akron, now nearing completion, is of 6,500,000-cu. ft. displacement and powered with eight independent engines of 600 hp. each. Its contract speed of 83.5 m.p.h. will make it the fastest, as well as the largest and most powerful, airship ever built. A similar airship, of revised design for commercial service and with a slight increase in displacement, can carry 80 passengers and 25,000 lb. of mail and express across the Atlantic. Such a commercial design has been used as the basis for our study of transoceanic airship services.

Favorable Locations for Terminals

The Weather Bureaus of the principal maritime powers are now collecting by radio daily weather reports from ships at sea and broadcasting weather maps and forecasts, so that now the navigator of an airship at sea should know what sort of weather to expect and plan accordingly. Our studies place great importance on this ocean weather service, which the advance in radio art has made possible.

One main terminal will be required on either side of the Atlantic, and these terminals will be completely equipped for overhauling, repairing and servicing the airships. Although for passengers the region near New York City is commercially most desirable, a preliminary study of wind and weather indicates that a less stormy location should be sought for the main terminal to minimize delays in departure. However, a mooring mast is expected to be erected near New York City at which airships can moor to discharge passengers and mail before proceeding to the main terminal to the south.

Weather records for the last 20 years have been analyzed for a large number of places between New York City and Georgia. These clearly show that locations on or near the coast are subject to high winds in winter and, in summer, experience winds of uncertain direction due to land and sea-breeze phenomena. Even Lakehurst, N. J., at which airship operations are satisfactorily handled by the Navy, now seems to be without the natural advantages for an airship harbor that can be obtained farther inland. The regions west of Chesapeake Bay and east of the mountains (Baltimore, Washington, Richmond) and the Delaware Valley (Philadelphia) escape the full force of ocean gales and are protected by the mountains from storms from the north and north west. Presumably, therefore, the main American terminal should be located somewhere in that region. In Europe, one very favorable location has been found in the Rhine Valley near Frankfort, Germany, which is somewhat nearer to Paris than to Berlin and not far by air from London. Because so many Americans buy their tickets to Paris, perhaps a first landing at a mooring mast should be made near Paris before proceeding to the main terminal.

Routes Worked Out for Five Years

The routes to be followed by the airships, say between Washington and Paris, will depend on the season of the year and the weather. Each trip is a particular problem in applied meteorology in which the captain will set his course to take advantage of favoring winds and to avoid head winds, sleet and bad weather. With complete radio service, the captain will draw his weather map each day and plot his course on it. This is a new method in navigation, developed by Dr. Eckener, in which the weather map is substituted for the mariner's chart and advantage is taken of storms to hasten the journey.

An extensive research into ocean weather has been conducted to forecast the average times of crossing, the reliability of any set scheduled crossing time, the reserve of fuel needed for the most unfavorable case and, in general, the routes to be followed. We were supplied by the Weather Bureau with daily weather maps for a five-year period regarded as typical of Atlantic weather. We assumed that an airship left Paris and one left Washington every Saturday night. We then gave to two investigators the problem of selecting the course for Sunday with one day's weather map before them. They were required to avoid freezing fog, violent weather disturbances and evidences of squally conditions and to take a course to make the best time. The altitude was to be 1500 ft., at which winds were expected to be 30 per cent stronger than shown on the chart. Then the weather map for Monday was disclosed and the next day's course set, and so on. Each of the 520 flights was thus a separate problem and gave the course followed and the time taken. The investigators worked independently and afterward repeated part of each other's work. The differences between courses and times made by the two investigators were no more than might be expected when two captains set out together in a race.

It was noted that in summer 80 per cent of the flights followed the northern or Great Circle course rather than a more southerly route. In winter only 3 per cent of the flights followed the Great Circle. Consequent seasonal variation in average flight duration is about 8 hr.

Winter and Summer Crossing Time

We then sought the maximum crossing time that would be required in each month for the whole five-year period. These times have been used as the basis of fuel reserves to be on board before commercial loading is allowed. Westbound in winter, fuel for four days at 65 knots should be provided, although the crossing time will usually be less than three days. A further reserve of 40 per cent is always available by slowing down by 10 knots. A practical degree of reliability is to be expected if the schedule is set as follows:

	Summer	Winter
Eastbound, hr.	58	64
Westbound, hr.	70	80

Such schedules will be met or beaten on more than 80 per cent of the crossings.

(*Concluded on p.* 222)

Oil Consumption as Affected by Engine Characteristics

Semi-Annual Meeting Paper

By H. C. Mougey[1]

THE PROBLEM of oil consumption must be solved before the problem of winter starting and winter lubrication can be solved, asserts the author, since winter starting and winter lubrication require light oils, and light oils give poor results as regards oil consumption.

Eight factors affecting oil consumption are listed in the order of their importance. Some of the reasons why they affect oil consumption are given and suggestions as to methods of overcoming the difficulties are made.

The author concludes that oils of low viscosity, which are required for winter starting, can be made to give satisfactory oil consumption at all engine speeds by necessary changes which probably will involve other mechanical features besides those usually considered in connection with design of the lubrication system. They may include improved bearings, oil-coolers, air-cleaners, oil-filters, better control of cylinder and piston cooling, and other factors. Certain changes in some of the lubricants themselves may be necessary. Much progress has been made in this work by both the oil industry and the automobile industry, and only by continued work and cooperation can success be attained.

One discusser of the paper believes that engine speed and oil leaks are the only factors of real importance affecting oil consumption, and points out that complete oil changes at 1000-mile intervals greatly reduce the miles obtained per quart. Cooperation of the oil companies is desired in making generally available in summer an oil that is suitable for use in the running-in period of new cars. Oil-coolers and improvements in bearing metals to increase their heat conductivity and heat resistance to enable them to sustain higher loads are expected to increase the safe temperature at which engines can be operated.

Results of tests made on the Indianapolis Speedway to ascertain the effect of speed and viscosity on oil consumption and of engine temperature on carbon deposition are given by another discusser.

Data obtained in tests of a passenger-car engine and a truck engine showed that engine variables, such as speed, timing of valves and ignition, and condition of the piston-rings, affect oil consumption much more than do the properties of the oil.

Extensive data obtained in cold-starting and oil-consumption tests are presented in a written contribution and appear to show the superiority of dewaxed zero-pour-test oils in resistance to viscosity change with temperature change, making one grade of oil instead of three suitable for both summer and winter operation.

FEAR of scored engines and burned-out bearings resulting from lack of sufficient oil on the bearing surfaces is the principal reason that the subject of oil consumption is of interest to the motoring public. However, many other troubles are associated with oil consumption, some of them very real and others of minor importance. A few years ago, excessive oil consumption usually was accompanied by fouled spark-plugs, bad carbon deposits, valve trouble, and the like, hence the public became prejudiced against high oil consumption. Most of these engine troubles have now been overcome, but the prejudice still persists.

Conservation of natural resources is another reason sometimes given for objecting to high oil consumption. Although the average annual oil consumption per car is about 20 gal., and the 26,000,000 cars in use in the United States consume a little more than 500,000,000 gal., this amount is insignificant compared with the large production of crude oil. The total amount of lubricating oil used for all purposes is only 3.7 per cent of the crude-oil production, and the lubricating oil used in automobiles is less than 1½ per cent.

Oil consumption is not very important from a cost standpoint. The cost of motor oil probably averages about one-fifth the cost of gasoline used in a car, and experience has shown that the American public is not very much concerned about the cost of gasoline.

The problems of starting and operating the engine in cold weather are other reasons for considering oil consumption, but the public does not seem to recognize them as oil-consumption problems. Many workers[2] have shown that, for the usual automobile, the viscosity of the undiluted oil should be less than 50,000 sec. at 0 deg. fahr. to enable the engine to be cranked. This oil, which is required for winter operation, will have a low viscosity under high-speed operating conditions in either winter or summer and will result in low mileage per gallon or high oil consumption under such conditions. As a result, the motorist uses oils of higher viscosity to obtain more miles per gallon and thus increases the starting and winter-lubrication problems.

The oil-consumption problem must be solved before cold-starting and winter-lubrication problems can be solved. This is the real reason that the automobile and oil industries as well as the public should be interested in oil consumption.

The factors affecting oil consumption, in the order of their importance, are:

(1) Engine speed
(2) Oil leaks
(3) Design of the lubricating system and changes due to wear

[1] M.S.A.E.—Assistant technical director, chief chemist, General Motors Corp. Research Laboratories, Detroit.

[2] See S.A.E. JOURNAL, February, 1928, p. 213, and TRANSACTIONS, vol. 23, p. 97; S.A.E. JOURNAL, February, 1931, p. 234; also *Automotive Industries*, March 7, 1931, p. 401.

(4) Viscosity of the oil
(5) Volatility of the oil
(6) Pour test
(7) Possibility of effects from carbonization of the oil-control rings
(8) Length of time between oil changes

Factors (4), (5), (6) and (7) are the only ones for which the oil companies are responsible. The automobile companies and the driving public are responsible for factors (1), (2), (3) and (8).

Oil consumption increases with speed in most engines. This is illustrated by the curves in Fig. 1, taken from a paper on piston-rings by Bramberry[3], and by Table 1, showing the consumption at various speeds of two different cars using two different oils.

TABLE 1—RESULTS OF OIL-CONSUMPTION TESTS ON TWO OILS AS AFFECTED BY ENGINE DESIGN AND SPEED AND VOLATILITY OF THE OIL

Oil Characteristics

	Oil *A*	Oil *B*
Viscosity at 100 Deg. Fahr., Saybolt sec.	322	322
Viscosity at 210 Deg. Fahr., Saybolt sec.	50	55
Flash-point, deg. fahr.	380	430
Fire-point, deg. fahr.	450	505
Color	4.5	5.0
Conradson Carbon, per cent	0.14	0.30
Pour Test, deg. fahr.	20	35

Comparative Mileages of Two Cars[a]

Miles per Gal. of Oil at	Car No. 1		Car No. 2	
	Oil *A*	Oil *B*	Oil *A*	Oil *B*
30 m.p.h.	1,860	Over 2,000	3,850	Over 4,000
40 m.p.h.	750	1,160	860	2,850
50 m.p.h.	320	460	290	470
60 m.p.h.	....	....	170	190

[a] Both cars have six-cylinder pressure-feed-lubricated engines but were made by different companies.

How Engine-Speed Affects Oil Consumption

Oil consumption is affected by engine speed on account of

(1) Decrease in viscosity of the oil with increase in temperature incident to high speed
(2) Failure of the piston-rings to scrape off the oil at high speed
(3) Increased amount of oil thrown on the cylinder-walls at high speed on account of
  (*a*) Increased oil pressure from the oil-pump due to higher pump-speed
  (*b*) Additional effect of the crankshaft as a centrifugal oil-pump in the case of engines having pressure lubricating systems[4]
  (*c*) Greater tendency of oil to leak past the connecting-rod bearings because of the lower viscosity of the oil incident to high temperature resulting from high speed.

These factors are all well known, even if their effects are not always appreciated.

Oil-Leak Effects Increased by Speed

Oil leakage includes:

(1) Liquid leakage at stationary joints of the crankpan with the crankcase, lubrication system fittings outside the crankcase, and so forth
(2) Mist and vapor losses at breathers, crankcase ventilators, oil-filling openings and other openings into the crankcase
(3) Liquid losses at joints where rotating members penetrate the crankcase, as at the front and rear crankshaft bearings and certain camshaft bearings.

These leaks are affected greatly by speed, because

(*a*) Vapor and fog are greater at high speed and high temperature.
(*b*) Viscosity of the oil is much lower because of the high temperature resulting from high-speed operation.
(*c*) Liquid losses at all openings are greatly increased by increased pressure inside the crankcase.

Most of this pressure difference (*c*) at high speed is caused by the vacuum outside the crankcase resulting from the movement of the engine through the air. This vacuum is similar to that behind a rapidly moving train or automobile or above the wing of an airplane. When a car has been driven on the road at high speeds and then the under part of the engine is examined, many oil drops and indications of oil leaks will be found. When the car is operated on the chassis dynamometer at corresponding engine-speeds, the oil leakage is greatly reduced. Frequently the mileage per gallon on the road at 60 m.p.h. will average only one-half to one-third of the mileage per gallon of the same engine on the chassis dynamometer. This pressure-difference

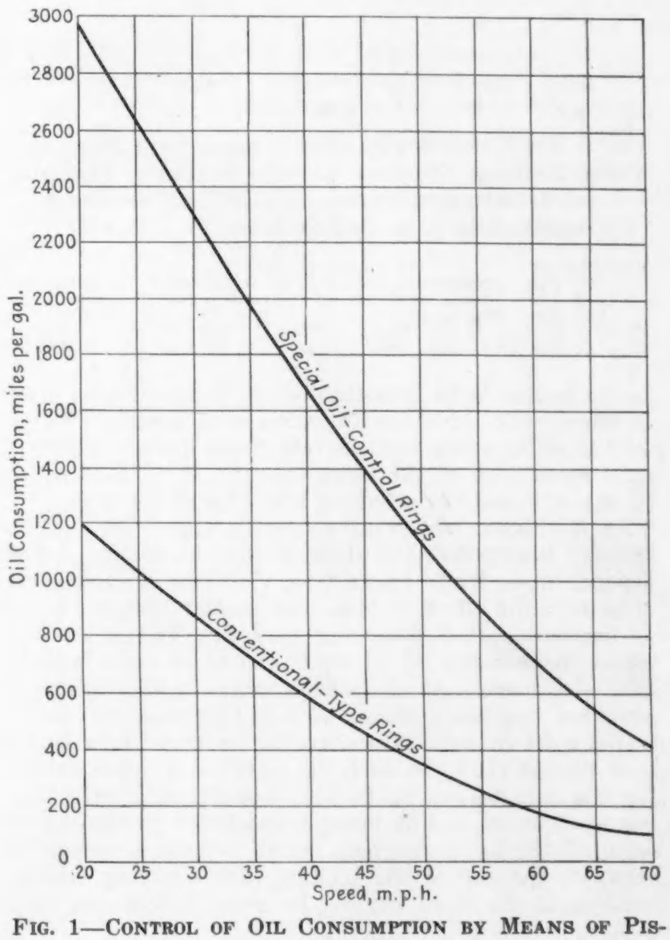

FIG. 1—CONTROL OF OIL CONSUMPTION BY MEANS OF PISTON-RINGS

These Curves Illustrate Well How Oil Consumption Increases in Most Engines with Increase of Car Speed

[3] See S.A.E. JOURNAL, November, 1928, p. 495; also TRANSACTIONS, vol. 23, p. 418.

[4] See THE JOURNAL, August, 1927, p. 127; also TRANSACTIONS, vol. 22, part 2, p. 25.

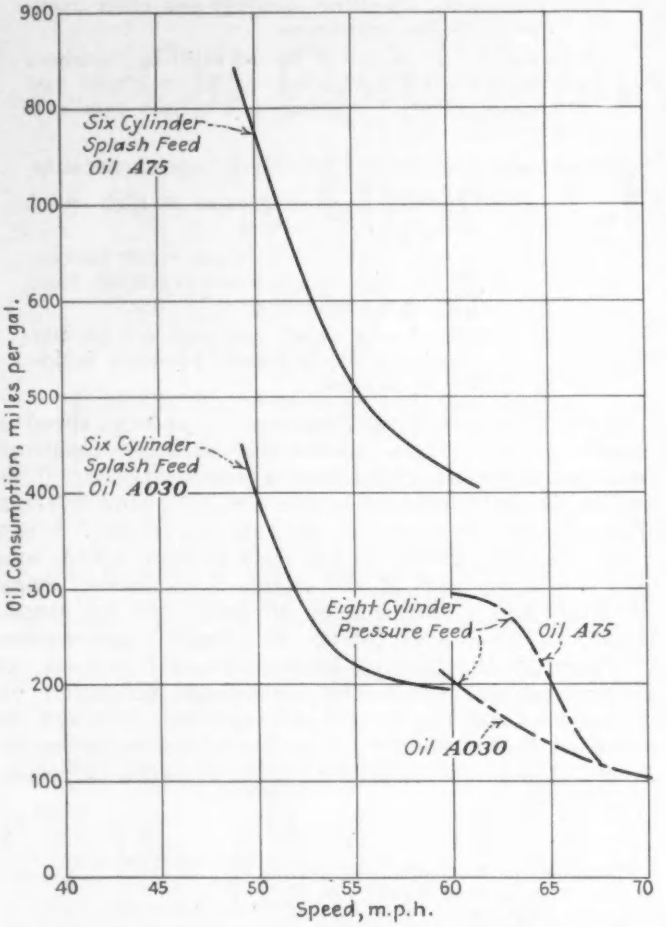

FIG. 2—OIL-CONSUMPTION CURVES FROM ROAD TESTS WITH THREE ENGINES, SHOWING EFFECTS OF THREE VARIABLES: (a) LUBRICATION SYSTEM, (b) OIL AND (c) SPEED

Specifications of the Two Oils Used Are as Follows:

	Oil A 030	Oil A 75
Viscosity at		
100 Deg. Fahr., sec.	265 to 340	760 to 1,010
130 Deg. Fahr., sec.	130 to 145	300 to 380
210 Deg. Fahr., sec.	47	70 to 80
Flash (minimum), deg. fahr.	340	440
Fire (minimum), deg. fahr.	385	550

factor begins to be important at 40 m.p.h. and increases in effect very rapidly with increase of speed. One has only to drive along the concrete roads in the country to gain some idea of the large amount of oil that is lost by leakage and the effect of speed on oil leakage.

In Michigan, where no maximum speed limit in the country is imposed, the speed at which cars are driven depends upon traffic congestion, visibility at curves and crossings, the effect of hills, and similar factors; and it is noticeable that wherever cars are driven at high speed the amount of oil on the road is much greater than elsewhere. At crossroads where traffic lights are provided the black streak of oil continues up to the traffic light in both directions but is very faint in the road beyond the light until the distance is great enough for the cars to get up to high speed again. On coming up a small incline beyond which the driver cannot see until the top is reached, the oil deposit is seen to be heavy to the top of the incline, then suddenly become faint until the road beyond becomes visible and high speed is again possible. A similar condition is noted at curves. The black oil-streaks also show that in entering a small town from the open country the speed is not decreased for some distance, although on the other half of the road, where traffic leaves the town, the streaks are almost absent. However, at railroad crossings, the streaks usually continue without any change in intensity except an extra-heavy deposit just beyond the tracks due to the bump and jar from crossing the rails.

Blow-by does not appreciably increase the pressure in the crankcase and is not an important factor in pressure differential between the inside and outside of the crankcase. Crankcase ventilators and other openings into the crankcase usually are so large that blow-by cannot build up pressure, but any changes involving closing these openings might permit blow-by to become important in this respect.

Effect of Lubricating-System Design and Engine Wear

Design of the lubricating system is a very general subject involving a large number of factors, some of which pertain only to pressure-feed systems, while others are common to both pressure and splash systems.

As an illustration of the differences in oil consumption with different cars, the records of some of those tested at the General Motors Proving Ground, where a number of cars of all makes are always under test, are given in Table 2. Figs. 2 and 3 show the effects of some of the different variables. The cars listed in Table 2 include both those made by the General Motors Corp. and by competitive companies. The figures were obtained from the records of the oil stockroom and do not take into account the differences due to speed or other driving conditions. However, in general, cars in the same price class usually undergo similar tests and are given similar treatment. Cars 1 to 16 inclusive have splash-feed lubrication systems. The others have pressure lubrication. The cars were all tested without taking up bearings, replacing piston-rings and the like, except in the case of Cars 7 and 10, which had the bearings taken up at approximately 20,000 miles. All cars are sedans or coaches with the exception of Car 14, which is a light truck. Cars 33 and 34 were operated on a special test over a definite route, combining all kinds of driving, good roads, bad roads, stops and grades. Both cars had identical service. The average speed over the entire time was 27½ m.p.h., but the cars were driven at varying speeds, without any extremely high speed.

These records show that, as a class, cars having pressure lubricating systems are worse in oil consumption than those having splash systems, and that, after the first few thousand miles, oil consumption increases with engine wear with both systems, although it may improve with wear while the piston-rings and other engine parts are wearing in.

A number of years ago Round[5] and Bull[6] showed that oil consumption was increased by factors that permitted more oil to be thrown on the cylinder-walls and was decreased by factors that permitted the oil to drain or be scraped from the walls. The amount of oil thrown on the cylinder-walls increases with speed, for reasons already given. Increasing the pressure on the piston-rings decreases oil consumption at high speed and also at low speed, as is illustrated in Fig. 1. This combination of high ring-pressure with decrease of oil on the cylinder-walls at low speed may result in undesirable

[5] See THE JOURNAL, June, 1922, p. 509; also TRANSACTIONS, vol. 17, part 2, p. 200.

[6] See THE JOURNAL, June, 1922, p. 513; also TRANSACTIONS, vol. 17, part 2, p. 158.

cylinder-wear, therefore engineers fear to go to extremes in trying to control oil consumption by means of piston-rings. Small clearances between the piston and the cylinder decrease oil consumption, especially at high speed where the piston-rings cannot follow the irregularities of the cylinder-wall.

Air-cleaners and oil-filters are valuable in decreasing oil consumption in that they reduce the quantity of dirt in the oil and thus decrease wear. Under some conditions, water on the cylinder-walls and bearings causes rust and rapid loss of metal. High percentages of sulphur in the fuel aggravate this condition[7]. Too low jacket-water temperature (below 110 deg. fahr.) permits contamination of lubricating oil by condensed water and aggravates this trouble[8]. The passage of insufficient air through the crankcase ventilators makes the ventilators less efficient and increases the trouble from water. Dirt introduced because of improper cleaning of the air entering the ventilator also aggravates the trouble. An oil-cooler or temperature regulator, with proper thermostatic control of the jacket-water temperature, enables the oil to warm up rapidly and thus helps crankcase ventilation and decreases the trouble due to water[9]. An oil-cooler also reduces oil consumption by limiting the maximum oil temperature, thus limiting the value to which the viscosity can drop.

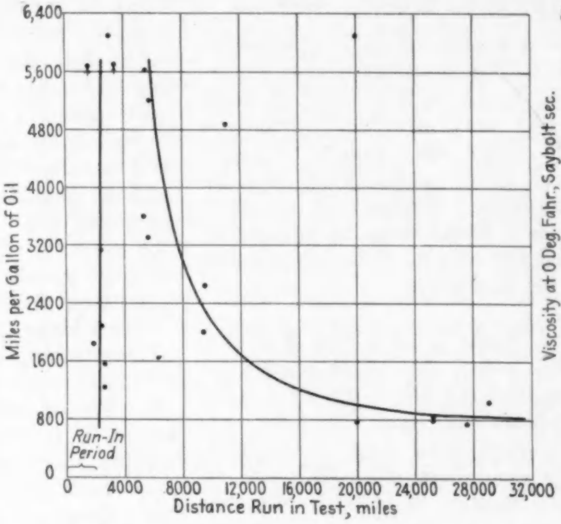

FIG. 3—AVERAGE OIL CONSUMPTION OF 19 DIFFERENT SIX-CYLINDER ENGINES, ALL OF THE SAME MODEL, HAVING SPLASH-FEED LUBRICATION

Each Dot Represents Average Mileage per Gallon for an Individual Car for the Distance Run as Indicated Directly below the Dot on the Scale of Miles. The Speed Schedule Was as Follows:

Miles	Speed, M.P.H.
Up to 500	20 to 25
500 to 1,000	25 to 30
1,000 to 2,000	35 to 50
After 2,000	40 to 45

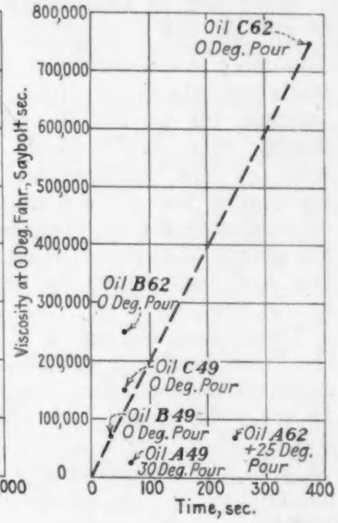

FIG. 4—TIME REQUIRED TO ESTABLISH LUBRICATION, AS AFFECTED BY VISCOSITY OF THE OIL AT PUMPING TEMPERATURE AND BY POUR TEST

Curve Plotted from Data Given by A. E. Becker

[7] See *Industrial and Engineering Chemistry*, January, 1928, p. 18.

[8] See THE JOURNAL, July, 1924, p. 47; also TRANSACTIONS, vol. 19, part 2, p. 58.

[9] See THE JOURNAL, April, 1931, p. 429.

TABLE 2—OIL-CONSUMPTION RECORDS FROM CARS TESTED AT THE GENERAL MOTORS PROVING GROUND

Car	Manufacturer	Cylinders	Test Started	Test Finished	Oil Used, S.A.E. Number	Total Miles	Oil Drained, Times	Miles per Gallon: Total Oil Used Plus Oil Drained	Miles per Gallon by 5,000-Mile Periods, Not Including Oil Drained: 0-5,000	5,000-10,000	10,000-15,000	15,000-20,000	20,000-25,000	25,000-30,000	30,000-35,000
1	*A*	4	3-31	4-31	20	3,620	6	453	2,230	....	....	....	....	....	....
2	*B*	4	1-31	2-31	30	5,063	4	596	1,620	....	....	....	....	....	....
3	*C*	6	11-30	1-31	20	5,000	3	702	1,735	....	....	....	....	....	....
4	*C*	6	11-30	2-31	20	5,002	3	910	3,570	....	....	....	....	....	....
5	*C*	6	11-30	3-31	20	18,009	10	1,017	4,570	4,360	2,400	....	....	....	....
6	*C*	6	11-30	3-31	20	13,058	7	1,244	....	10,000	....	....	....	....	....
7	*C*	6	11-30	3-31	20	29,061	16	904	3,200	5,330	4,000	1,920	2,330	....	....
8	*C*	6	11-30	4-31	20	22,000	12	800	2,670	2,910	1,714	1,410	....	....	....
9	*C*	6	11-30	4-31	20	34,000	18	918	4,800	5,340	5,330	2,910	3,000	1,390	1,000
10	*C*	6	11-30	3-31	20	25,000	14	757	2,000	6,000	5,720	648	1,525	....	....
11	*C*	6	11-30	12-30	20	12,000	7	906	2,000	6,860	....	....	....	....	....
12	*C*	6	12-30	1-31	20	14,033	7	1,040	1,435	6,740	3,200	....	....	....	....
13	*C*	6	2-31	3-31	20	8,559	8	611	1,715	3,550	....	....	....	....	....
14	*D*	6	2-31	4-31	20	15,142	7	606	740	1,230	960	....	....	....	....
15	*E*	6	12-30	2-31	20	5,691	7	517	1,480	....	....	....	....	....	....
16	*F*	8	12-30	2-31	30	5,025	3	468	980	....	....	....	....	....	....
17	*G*	6	1-31	4-31	20	6,987	9	328	740	510	....	....	....	....	....
18	*G*	6	12-30	4-31	30	10,500	14	392	1,330	2,000	....	....	....	....	....
19	*G*	6	12-30	2-31	30	14,698	18	417	1,725	1,540	1,380	....	....	....	....
20	*G*	6	2-31	3-31	30	10,000	13	339	695	1,000	....	....	....	....	....
21	*H*	8	1-31	4-31	30	6,054	5	465	970	....	....	....	....	....	....
22	*H*	6	1-31	3-31	30	6,160	5	502	1,020	....	....	....	....	....	....
23	*I*	6	1-31	3-31	30	5,080	4	452	925	....	....	....	....	....	....
24	*I*	8	1-31	3-31	30	6,062	5	472	1,030	....	....	....	....	....	....
25	*J*	8	1-31	4-31	30	5,028	4	457	1,180	....	....	....	....	....	....
26	*K*	6	2-31	3-31	30	4,374	2	650	1,665	....	....	....	....	....	....
27	*K*	8	2-31	4-31	30	5,189	4	457	830	....	....	....	....	....	....
28	*L*	6	1-31	3-25	30	5,000	2	834	1,665	...	....	....	....	....	....
29	*M*	8	1-31	3-31	30	5,635	9	268	2,650	....	....	....	....	....	....
30	*M*	8	1-31	4-31	30	6,022	10	359	1,855	....	....	....	....	....	....
31	*M*	6	1-31	3-31	30	5,627	6	395	920	....	....	....	....	....	....
32	*N*	8	1-31	3-31	30	4,956	5	397	1,165	....	....	....	....	....	....
33	*O*	8	1-31	4-31	20	40,122	21	342	1,350	927	870	757	454	453	405
34	*O*	8	1-31	4-31	20	34,165	17	488	2,270	2,000	1,000	1,040	875	785	628
35	*P*	8	1-31	4-31	30	5,100	5	345	950	....	....	....	....	....	....
36	*Q*	8	2-31	3-31	30	5,050	2	459	720	....	....	....	....	....	....
37	*R*	8	2-31	3-31	30	5,074	4	290	655	....	....	....	....	....	....

Time Lag in Delivering Oil to Bearing Surfaces

All lubricating systems are subject to a greater or less delay in delivering oil to the bearings and cylinder-walls on starting, although in splash-feed systems residual oil in the troughs may provide lubrication during this period. This delay may result in rapid wear of the bearings and other parts, thus rapidly increasing the oil consumption. Becker, in a paper on cold starting of engines[10], gives data in regard to the length of time required for oils of different viscosities and pour-points to be delivered to the bearings at low temperatures.

These data are shown in Table 3, and Fig. 4 shows the same results in graphic form. Attention should be called to the long time required for Oil C-62, an S.A.E. 40 oil with a zero pour-test, and for Oil A-62, an S.A.E. 30 oil with a +25-deg. pour test. Oil A-49 (S.A.E. 20), which has a pour-test of +30 deg., is not so bad in this respect, because it is lower in viscosity.

It is apparent that the use of oils that are too high in viscosity or in pour-test, or both, results in little or no lubrication of the engine on starting, and the periods of time that this insufficient-lubrication condition exists may be quite long. Many schemes to shorten this period have been proposed. An early inventor tried to solve this problem by means of holes in the splash troughs, arranged so that oil fed slowly into the troughs from below. When the engine was running, just enough oil leaked into the troughs to provide regular splash lubrication, but when the engine was idling sufficient oil flowed through the holes to fill the troughs and thus gave copious lubrication immediately on starting, with normal lubrication under running conditions.

Many patents have been granted on means of delivering oil directly to the cylinder-walls under pressure immediately on starting instead of waiting for it to leak past the connecting-rod bearings and be thrown on the walls. Pulling out the choke, stepping on the starter, or other motions incidental to starting have been suggested as methods for automatically operating devices to provide this lubrication, but, if the pump cannot build up pressure and deliver oil through the regular system, these special devices fail. Clayden[11] proposes introducing oil into the intake manifold by means of an automatic device that operates only on starting, and many other upper-cylinder oilers feed oil into the intake manifold and operate both while running and during starting conditions. Upper-cylinder lubrication can be obtained much more simply when needed by mixing a small quantity of oil in the gasoline. Since our object is to decrease oil consumption at high speed, this addition of oil to the gasoline is not a solution of the problem, but with new cars, driven only at slow speeds during the run-in period, it may be valuable. A system of splash lubrication, on starting, from troughs full of oil, together with regular pressure-lubrication after normal running conditions have been established, is another of the suggestions offered as a solution of this problem.

In some cases, changes in the oil-pump inlet systems to shorten this initial period of insufficient lubrication involve means of bypassing the oil screen if it offers too much resistance to flow of the cold oil. Floating oil-inlets have been adopted by some companies, and various other devices have been used by others.

Spit-holes are frequently drilled in the connecting-rod bearings to help in getting oil to the cylinder-walls at low speeds. These holes act to increase the leakage past the connecting-rods and to direct this oil toward the cylinder-walls, but, as they are much more effective at high speed than at low speed, they increase oil consumption at high speed.

Variations in end clearance and in diameter clearance of connecting-rod bearings affect oil consumption, and, if these clearances are depended upon to meter the quantity of oil thrown on the cylinder-walls, the quantity will increase as the bearings wear. This change due to wear is provided for in some cars by metering the oil at the crankshaft by regulating the size of the hole through which the oil enters the connecting-rod bearing and then providing a free outlet at the bearing by means of suitable grooves and slots. With such a system, wear of the connecting-rod bearings does not result in an increase in the amount of oil that flows through them and is thrown on the cylinder-walls[12]. Baffles to limit the oil thrown on the cylinder-walls have been tried, but the rapid air movements initiated by the pistons greatly interfere with this effect.

TABLE 3—TIME LAG IN DELIVERING OILS OF DIFFERENT VISCOSITIES TO BEARINGS AT LOW TEMPERATURES

S.A.E. Number[a]		Oil	Viscosity, Saybolt Sec., at Deg. Fahr. 100	130	210	0[a]	Pour-Point, Deg. Fahr.	Time Required To Establish Flow of Oil at 0 Deg. Fahr., Sec.
(Lower Limit)	20	*A*-49	236	120	49	22,000	30	65
(Center)	30	*A*-62	474	212	64	70,000	25	246
(Center)	20	*B*-49	298	137	49	70,000	0	32
(Near Top)	30	*B*-62	603	240	62	250,000	0	56
(Center)	20	*C*-49	361	153	50	150,000	0	56
(Low Limit)	40	*C*-62	755	270	61	750,000	0	Approx. 375

[a] Calculated from data published by Becker.

Some automobile companies try to control oil consumption by working on the registry of the lubricating grooves on the main bearings. By decreasing this groove from 360 to 180 deg. or even 90 deg., the quantity of oil pumped to the connecting-rods is decreased. Since this works at all speeds, trouble is experienced from insufficient lubrication at low speeds, and the oil pressure is then increased to cure this trouble. The resulting over-lubrication at high speeds is then remedied by again decreasing the length of the oil groove. It is possible to continue this vicious circle for many months without making any progress.

As reducing the oil pressure decreases the quantity of oil thrown on the cylinder-walls, tests were started in our laboratory to try to control oil consumption by controlling the oil pressure. We soon found that there was a limit below which reduction in oil-pump pressure had little effect, because the crankshaft acts as a centrifugal oil-pump in series with the regular oil-pump and at high speed develops rather high pressures if it is supplied with oil. Brooks and Sparrow[13] show a pressure as high as 78 lb. per sq. in. at 4000 r.p.m., developed by the crankshaft independently of the oil-pump.

A very old idea is to lubricate the main bearings by pressure and depend more or less on the centrifugal-

[10] See *Automotive Industries*, March 7, 1931, p. 401.

[11] United States Patent No. 1,628,117, issued to A. L. Clayden.

[12] See THE JOURNAL, September, 1922, p. 233; also TRANSACTIONS, vol. 17, part 2, p. 212.

[13] See THE JOURNAL, August, 1927, p. 127; also TRANSACTIONS, vol. 22, part 2, p. 25.

pump action of the crankshaft to lubricate the connecting-rods, with leakage from the connecting-rods supplying the cylinders. In the more common form in which this idea was used, the oil was delivered to a ring attached to the crankshaft at one end of the main bearing. Centrifugal force pumped the oil from the ring to the rod bearings. It appears that, by means of suitable changes in design, it should be possible to overcome the disadvantages of the ring oiler and retain its advantages. This would make the effect of oil viscosity of much less importance and such a system might give as high mileage per gallon with a light oil as a conventional system with heavy oil.

The problem of oil leaks must be solved before oil consumption is controlled. This is true regardless of the lubricating system used.

For many years the Skinner system has been used to suck oil off the cylinder-walls and thus improve the oil consumption. Round mentions[14] the use of a very similar system for this purpose. By applying suction

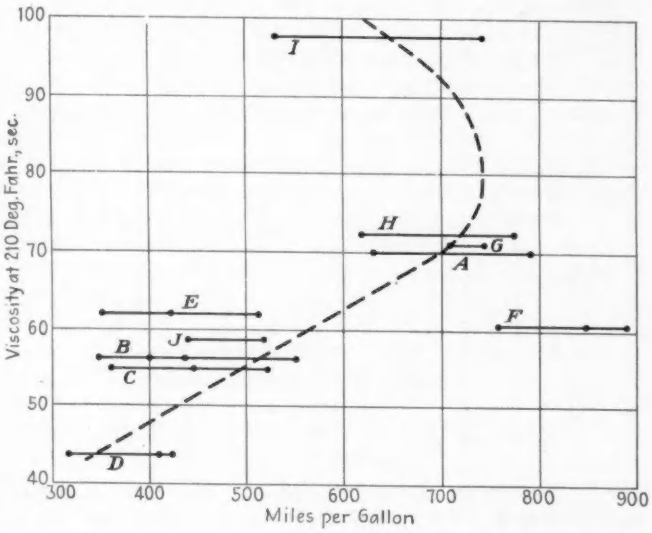

FIG. 5—RELATION OF OIL CONSUMPTION TO VISCOSITY DATA FROM CHASSIS-DYNAMOMETER TESTS. LETTERS REFER TO DIFFERENT OILS

to the entire crankcase or to the individual areas where leaks occur, it seems that the troubles due to leakage can be overcome. Of course, all unnecessary leaks, such as those at the joints of the crankpan and crankcase, should be stopped by better construction or maintenance, or both.

Relation of Oil Viscosity to Consumption

So far I have discussed only factors that are beyond the control of the oil companies. The oil companies can do some things to help. As regards the oil, the principal properties in the order of their importance are viscosity, volatility, pour test and the possibility of effects from deposition of carbon on the oil-control rings.

Fig. 5 shows the relation of oil viscosity to consumption. High viscosity decreases the quantity of oil thrown on the cylinder-walls and that lost by leakage. However, it increases the difficulty of removing or draining the oil from the cylinder-walls. Where these two opposed factors cross indicates the maximum gain in the reduction of oil consumption through increased viscosity. Further increases in viscosity result in fewer miles per gallon.

Oil viscosity is of great importance because of the unavoidable changes in viscosity due to the wide temperature range to which the oil is subjected. The oil-temperature range is less for summer than for winter driving conditions, especially in cars fitted with radiator shutters; and for this reason the changes in viscosity cause more trouble in winter than in summer. The minimum oil temperature corresponds with the minimum atmospheric temperature. As was previously shown, the viscosity of undiluted oil at the minimum atmospheric and oil temperatures must not exceed about 50,000 Saybolt sec. to allow of cranking the engine when cold. The extreme temperature ranges in winter between low atmospheric temperature and high oil temperature with oils of not over 50,000 sec. at zero or sub-zero results in oil of very low viscosity at high temperatures, thus greatly increasing oil consumption at high speeds because of low viscosity.

Dilution in the crankcase helps in reducing the viscosity of the oil on the cylinder-walls at low temperatures, thus making the value of 50,000 sec. for the undiluted oil in the can a possibility for cold-starting. However, dilution is not a complete solution of the problem, since driving at high speeds and temperatures removes dilution, thus raising the viscosity of the oil and making cold-starting the following morning difficult or impossible. Correct use of the oil-temperature regulator, by limiting the maximum oil temperature and thus limiting the minimum oil viscosity when hot, increases the miles per gallon of oil as well as permits the use of a lighter oil when cold, thus improving cold-starting conditions.

Oil consumption is increased by bearing wear, the pounding out of babbitt bearings or the flow of thick babbitt bearings resulting from high loads at high temperatures. An oil-cooler decreases these effects, thus improving oil consumption during the life of the car. The value of an oil-cooler in helping to solve these oil-consumption problems was pointed out by Ramsaur[15]. Although the invention or development of bearings that will resist pounding out or wear at high temperatures will be a solution of this part of the problem, the high oil consumption due to low-viscosity oil resulting from high temperature will remain. Thus, change in bearing composition is not a complete solution of the problem, unless it is accompanied by changes in the lubricating system to give low oil consumption with light oil.

The greatest possible change that oil companies can make in viscosity-temperature slope between oils of extreme differences in crudes and in refining methods is approximately 15 deg. fahr, for 100 deg. temperature range for oils matched as to viscosity at 100 deg. fahr., using oils of viscosity ranges that are possible for cold-starting. For example, an oil of the flattest viscosity-temperature slope that has a viscosity of 50,000 sec. at 0 deg. fahr. will have a viscosity of 350 at 100 deg. fahr. An oil of the steepest viscosity-temperature slope having the same viscosity of 350 sec. at 100 deg. fahr. will have a viscosity of 50,000 sec. at +15 deg. fahr. A similar difference of about 15 deg. exists for the temperature range above 100 deg. fahr. as is illustrated for the temperature range below 100 deg. fahr. (See Fig. 6.)

The oil companies stress this difference of viscosity

[14] See THE JOURNAL, June, 1922, p. 509; also TRANSACTIONS, vol. 17, part 2, p. 200.

[15] See S.A.E. JOURNAL, April, 1931, p. 429.

TABLE 4—RATE OF FLOW OF AN OIL THROUGH SAYBOLT VISCOSIMETER AT DIFFERENT TEMPERATURES AND PRESSURES

Properties of the Lubricant[a]

Specific Gravity at 60 Deg. Fahr.	0.897
Viscosity at	
0 Deg. Fahr. (calculated from curve), Saybolt sec	6,000
80 Deg. Fahr., Saybolt sec.	225
100 Deg. Fahr., Saybolt sec.	135
130 Deg. Fahr., Saybolt sec.	82
210 Deg. Fahr., Saybolt sec.	43.5
Pour Test, deg. fahr.	+35

Rate of Flow under Additional Pressure Produced by a Column of Kerosene

Head of Kerosene, in.	Grams Delivered per Minute at 36 Deg. Fahr.	Grams Delivered per Minute at 25 Deg. Fahr.
0	1.3	0
5	3.3	0
10	5.3	0.04
15	7.3	0.41
20	9.3	0.44
25	11.4	0.47

[a] The lubricant was a commercial oil bought under the name of spindle oil.

temperature-range very greatly, as it is the principal factor in differences between competitive oils, but this difference of 15 deg. fahr. is really small compared with the possibilities of decreasing the oil temperature-range by the use of an oil-cooler. For example, as shown in Fig. 6, oil of 50,000 sec. viscosity at 0 deg. fahr. with the flattest viscosity-temperature slope will have a viscosity of 44 at 250 deg. fahr. By reducing the maximum oil temperature from 250 to 210 deg. fahr., an oil having the steepest viscosity-temperature slope and the same viscosity of 44 at this maximum of 210 deg. temperature will have a viscosity of 50,000 sec. at 0 deg. fahr.

Volatility as a Factor in Consumption

Volatility of the oil increases oil consumption at high temperatures, as is well known. The fact is mentioned by Round[16]. The following comments are taken from the Tide Water Oil Co's book on Veedol, published in 1920:

> If a lubricating oil contains a large portion of low-boiling-point constituents, the loss of oil vapors will be proportionately high when it is used in an engine, and vice versa. Some loss will always occur, but the choice of the right oil will reduce such needless waste to the minimum and be a guarantee of a reasonably low specific consumption, good lubrication and practically carbon-free conditions within the explosion chambers. The degree of volatility which lubricating oils should have is entirely determined by the maximum operating temperatures of the engine and by the character of its load, full or variable.

Our tests indicate that this difference in volatility of oils of normal composition is of little or no effect if the crankcase-oil temperature does not exceed 170 deg. fahr. The effect of volatility increases as the maximum oil temperature and the volatility of the oil increase. According to Livingstone and Gruse[17], a motor oil should be non-volatile at cylinder-wall temperatures but volatile at combustion-chamber-wall temperatures. In the tests reported by Haslam and Bauer[18], differences in volatility of the oils tested did not make more than 33-per cent difference in the oil consumption. This effect of volatility is a minor factor in most cases. An oil-cooler makes it possible to decrease or eliminate this effect by limiting the maximum temperature of the oil.

Pour-Point Affects Bearing Wear

Pour test affects oil consumption by its effect on the wear of the engine. Oil at a temperature more than a few degrees below its pour test does not flow to the pump inlet, since the viscosity in this condition, when measured under low pressure such as that which caused the oil to flow to the inlet, is very high. The rate of flow of a certain oil through the Saybolt viscosimeter, measured at several different temperatures and pressures, is shown in Table 4. It will be noted that when the lubricant was 10 deg. below its pour-point, it actually flowed in the Saybolt universal viscosimeter with an additional head produced by only 10 in. of kerosene.

The A.S.T.M. pour test may be described as the temperature at which an oil has infinite viscosity when

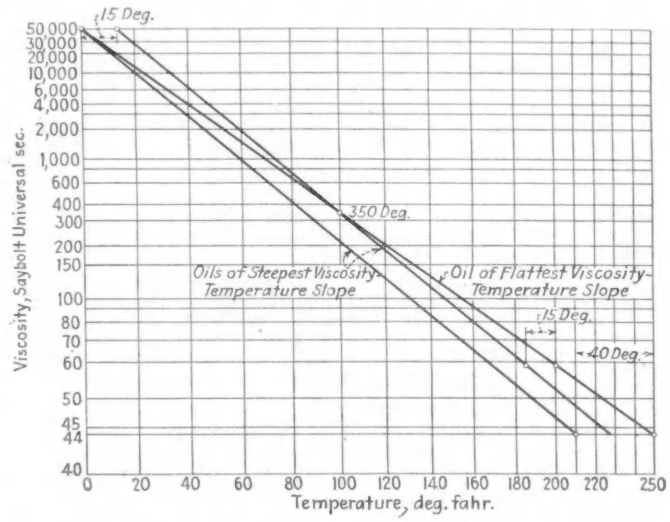

FIG. 6—MAXIMUM POSSIBLE CHANGES THAT OIL COMPANIES CAN MAKE IN THE VISCOSITY-TEMPERATURE SLOPE OF DIFFERENT OILS

For Oils Matched as to Viscosity at 100 Deg. Fahr. and of a Viscosity Range Suitable for Cold-Starting, the Greatest Change That Oil Companies Can Make in the Viscosity-Temperature Slope between Oils of Extreme Differences in Crudes and Refining Methods Is Approximately 15 Deg. Fahr. for a Temperature Range of 100 Deg. Fahr.

the viscosity is determined under a pressure head of almost zero according to definite A.S.T.M. conditions. That this effect of pour test disappears almost entirely when the oil is under pressure on the discharge side of the pump is true, but the effect may be enormous in decreasing the flow of the oil to the pump inlet and throughout the lubricating system. The oil industry deserves great credit for the progress it has made in lowering the pour test on motor oils, but some oil companies are still putting on the market winter oils having high pour-points. Anything that the automobile engineer can do by means of design of the lubricating system to decrease the importance of the pour test will help in decreasing trouble that the car owner may have, and decreasing the wear from this cause will help in solving the problem of oil consumption.

Possible Effects of Oil-Control-Ring Carbonization

While oil-control rings are designed to help in removing oil from the cylinder-walls, a possibility exists that carbonization of oil-control rings, with blocking of the

[16] See THE JOURNAL, June, 1922, p. 509; also TRANSACTIONS, vol. 17, part 2, p. 200.
[17] See *Industrial and Engineering Chemistry*, vol. 21, 1929, p. 904.
[18] See S.A.E. JOURNAL, March, 1931, p. 307.

holes and oil slots and sticking of the rings in the piston grooves, will decrease the effectiveness of the rings, thus increasing oil consumption. Assumption of this possibility seems very reasonable, but very few real data are available on this subject or on the relation of physical and chemical properties of the oil to the possibility of formation of carbon in the rings. Temperature and rate of oil-flow seem to be more important than the chemical properties of the oil. Formation of carbon in the rings and ring grooves is greatly decreased by better cooling of the piston and rings. Increasing the flow of oil through the holes and clearances of the piston-rings tends to wash out the carbon as it is formed and thus to decrease the deposition of carbon in the oil-control rings. This subject of carbon in the rings is so little understood that it is uncertain how much can be done to solve it by either the oil industry or the automobile industry.

Length of Time between Oil Changes

The desirable length of time between oil changes is a question on which a difference of opinion exists. If an engine should show 3000 miles per gallon on a test and require 6 qt. of oil to fill the crankcase, and if the crankcase should be drained every 500 miles and fresh oil put in, the oil consumption of this car would be 6 qt. per 500 miles, or 333 miles per gallon instead of the 3000 miles per gallon shown by the test. This fictitious value of 3000 miles per gallon is thus shown to be of academic rather than practical interest.

A general idea seems to prevail that if the public is educated to drain the crankcase oil frequently it will use very large quantities of oil and the market for lubricants will be increased. Under usual driving conditions, an oil change every 1000 or 2000 miles appears to result in throwing away from one-half to two-thirds of all of the oil the car owner buys. This is shown by the data in Table 2. However, the effect of oil changes is of less importance when high-speed operation of the engine is considered. The engine which is assumed to have shown 3000 miles per gallon on the test may show only 300 miles per gallon or less when it is operated at speeds in excess of 55 m.p.h. At speeds of 60, 65 and 70 m.p.h. the mileage per gallon may be much less. Any ordinary frequency of oil drainage would have little effect on the quantity of oil consumed under these conditions. With an engine giving 200 miles per gallon at 60 m.p.h., oil is passed through the engine at the rate of 1 gal. every $3\frac{1}{3}$ hr. Tests at maximum speed on passenger-car engines now on the market, with the engines in good condition, sometimes show rates of oil consumption as high as 1 gal. per hr. Under these conditions of very high oil consumption at high speed, draining of the crankcase and filling it with fresh oil has little effect on either total oil consumption or the composition of the oil in the crankcase.

When a car is driven at the high speeds at which high oil consumption is to be expected, the owner should try to maintain the crankcase oil level at the "full" mark instead of letting it get low on the assumption that in a short time the crankcase will be drained and the oil in it discarded. In most cases in which the oil is a factor in burned-out bearings, the cause is an absence of oil of any kind rather than the properties of the oil that was *not* in the bearings.

One serious objection to draining the crankcase oil, especially in the winter, is the difficulty that is likely to be encountered by having oil of too high viscosity in the engine for cold-starting. Oil in use has a percentage of dilution, and even 10 per cent in an oil of ordinary viscosity required for winter driving will decrease the viscosity at 100 deg. fahr. to about one-half its value. If the crankcase is drained and an oil which is not prediluted is put into the engine, this oil, before it becomes diluted by service, may have a viscosity so great that it will make starting difficult or impossible. In addition, on account of its high viscosity, it will make the establishment of lubrication after cold-starting very slow. The danger caused by draining the crankcase in cold weather and filling with fresh undiluted oil has been pointed out by previous workers on this problem[19]. This interference with the establishment of lubrication may result in rapid wear or even sticking-up of the engine, and these mechanical troubles, if extended over the life of the car, would greatly increase the oil consumption.

In conclusion, it is apparent that the problem of oil consumption must be solved before the problems of winter starting and winter lubrication can be solved. Oils of low viscosity that are required for winter starting can be made to give satisfactory oil consumption at all engine-speeds by the necessary changes. In all probability these changes will involve other mechanical features besides those usually considered in lubrication design. They may include improved bearings, oil-coolers, air-cleaners, oil-filters, better control of cylinder and piston cooling, and other factors. Certain changes in some of the lubricants themselves may be necessary. Much progress has been made in this work by both the oil industry and the automobile industry, and it is only by continued work and cooperation by and between these two industries that final success can be attained.

THE DISCUSSION

ALEX TAUB[20]:—Throughout his paper Mr. Mougey has emphasized the desirability of using the lighter oils but that increased oil consumption stands between us and this ideal. He has rightfully given considerable space to the various causes responsible for this condition, but I believe that only two of the eight factors listed are of any real importance, and they are interrelated. These are engine speed and oil leaks. The greater the engine speed is, the more oil will leak out of a given spot regardless of whether differential pressure within and without the oil-pan is responsible.

It is of interest to deal briefly with this problem quantitatively. Certainly not less than 250 miles per quart would be regarded as a good oil consumption rate, yet a high percentage of the driving public makes a complete oil change after 1000 miles of driving. Assuming that oil is not added during this driving period, the consumption is, with 6 qt. of oil in the engine at

[19] See *Automotive Industries*, March 7, 1931, p. 401, and THE JOURNAL, February, 1926, p. 163; also TRANSACTIONS, vol. 21, part 1, p. 81.

[20] M.S.A.E.—Development engineer, Chevrolet Motor Co., Detroit.

the start, approximately 166 miles per quart. The motorist given to this method of engine oiling does not complain, because he is not conscious of oil consumption as it affects his cost of operation. The difficulty lies in the state of mind of the motorist between the times of oil change. If he is aware that his oil is likely to become dangerously low on short trips, he becomes dissatisfied and accepts the ill-considered advice from oil-station attendants and uses heavier lubricants that are unsuited to the powerplant he is operating. He thus corrects an error with an evil and changes a petty continuous worry into a major or collective worry when he discovers premature piston-pin and cylinder-bore wear due to under-oiling at starting and conservative speed and sticky valves under hard driving.

Consideration of oil leaks and their part in oil consumption is also of interest. A teaspoonful of oil leaking out per mile of car travel amounts to 1 qt. of oil in 200 miles, even if no oil were being consumed by normal engine operation. If, in addition, normal operation consumes oil at the rate of 1 qt. per 400 miles, which is rather an ideal figure, as we must have oil on the piston-rings, the over-all consumption is approximately 1 qt. per 144 miles. Where we must work for improvement therefore becomes quite obvious.

With this figure of oil consumption, it is quite possible that in 1000 miles the car owner may add 5 qt. of oil, and if he changes oil at this point, he arrives at an oil consumption of 1 qt. per 90 miles.

Suitable Oils Should Be Available Throughout Summer and Winter

This brings us to the unfortunate situation brought about by variation between oils used in engines and oils recommended by the engineering departments of the various vehicle manufacturers. Surely greater cooperation is needed between oil men and car engineers. Oil specifications are determined by the engineering department on a basis of engine operation, and if the recommended type of oil is used the engineering department can intelligently use its field for information to modify the specifications or the design of the company's products.

Nothing will throw the field picture out of balance as quickly as will an unsuitable oil. For instance, mixing penetrating oil in the lubricant used for running in may easily give an early run-in feeling. Actually, the bores may be run in but the bearings are still too tight for high-speed work. The run-in is unbalanced, and, with a large production, this may be productive of trouble.

The Chevrolet Motor Co. recommends an S.A.E. 20 oil having a zero pour-test for running in. No difficulty is met in obtaining this oil in the winter, since the oil companies are not anxious to assume the responsibility for starting difficulties; but this oil is not easily obtained in the summer. Perhaps a vigorous campaign conducted by the car manufacturers regarding the proper oils to use would help to make the oils recommended by the factory available at all times when they should be used.

Chevrolet specifications call for the use of S.A.E. 20 oil in summer and S.A.E. 20 with a zero pour-test in winter, after the first 500 miles of driving. The winter oil is available and is recommended by oil companies, but in the summer the picture is different. Examining the recommendations of 14 oil companies, we find that 5 specify S.A.E. 40, 6 specify S.A.E. 30 and 2 specify S.A.E. 20. One oil company specifies neither fish nor fowl, since its number is 40 and the oil is equal to an S.A.E. 20, yet the viscosity may be anywhere between these two, depending upon how hard a car is being driven. We recommend an S.A.E. 30 for hard driving in summer, which means a split specification, but is not entirely out of order, as three oil companies offer split specifications.

This condition of varying specifications is disturbing. Oil consumption and competition are the alibis offered. Even with the oil as specified by our engineering department, the oil consumption of the particular product I am discussing averages fairly high, the figures being somewhere between 300 and 400 miles per quart for high-speed driving. Here again, perhaps a vigorous campaign to the public as to the right oil to use may bring about a little consistency.

The conditions outlined are, of course, specific and refer to a particular car. Those that exist in relation to other cars and in different price classes probably vary with the duty and the design.

Improvements in Bearings Coming

I believe that we are facing a new era in bearing life or load-carrying ability. The oil-cooler, as pointed out by Mr. Mougey, is serving to make bearings safe without interfering with bore, piston and valve lubrication, which usually are sacrificed when the oil viscosity is increased to help the bearing. Likewise, new thoughts and developments are going on with reference to bearing metals which will serve to increase the safe temperature at which we can operate engines. I refer specifically to the development work on bearing metal at the Cleveland Graphite Bronze Co.'s laboratories.

All of the present bearing difficulties begin in a localized area, and present bearing materials, such as babbitt, soften rapidly with heat. By increasing the heat conductivity of the lining, we tend to eliminate the possibility of local heating, for if the heat can be more widely distributed the local spot will be relieved. If we add to this improvement the further advantage of a metal that is harder under high temperature than the present bearing lining, we shall have a more uniform surface to support the load and thus reduce the unit pressure.

The effective temperature of the oil in the bearing is not easily determined. It is usual in pressure-feed engines for the oil to enter the bearing locally and leave it at a point close to the entrance; that is, considering the bearing in its length. This oil-flow has very little chance to affect the temperature of the oil in the bearing. It is really necessary to flow the oil through the bearing and build a sufficient oil control at the piston to meet this condition.

Should Acquaint Car Owners with the Facts

R. E. WILKIN[21]:—We recently completed a series of tests at the Indianapolis Speedway with 13 makes of 1931-model passenger-cars. The tests were started after a 2000-mile run-in and consisted of several runs of 1000 miles at 30 and 55 m.p.h. Constant speed was maintained during a test, the car being stopped only for oil and fuel or for repairs. At the end of each 1000-mile test, the engine heads were removed, the carbon cleaned out and the valves ground if necessary. These tests gave us very interesting information on the effect of

[21] M.S.A.E.—Sales engineer, technical division, lubricating department, Standard Oil Co., (Indiana), Chicago.

speed and oil viscosity on oil consumption, gasoline consumption and engine carbon.

The test to determine the effect of speed on oil consumption included two runs of 1000 miles at 30 m.p.h. and two runs at 55 m.p.h. on the same oils of summer grades. The average quantity of oil used for each car for 1000 miles was 1.0 qt. at the slower speed and 6.9 qt. at the higher speed. This ratio of 1.0:6.9 varied with individual cars from a minimum of 2.3 to a maximum of 19.8. It is interesting to note also that the increase in gasoline consumption at the higher speed was approximately 25 per cent.

To ascertain the effect of viscosity on oil consumption, three 1000-mile runs were made at 55 m.p.h. on three different grades of oil varying from fairly light to very heavy oil, and the following results were obtained as fleet averages:

S.A.E. No.	Viscosity at 210 Deg. Fahr., Saybolt Sec.	Oil Consumption, Qt. per 1,000 Miles
30	58	9.84
50	83	7.11
60	107	5.66

This increase in consumption of the light oil over heavy oil was only 74 per cent, instead of several hundred per cent, as is generally thought by the driving public. At the same time, a decrease in gasoline consumption of 6.4 per cent was obtained with the lighter oil; in fact, the cost of the additional oil used was cancelled by the gasoline saved.

The effect of speed, or of temperature resulting from speed, on combustion-chamber deposits was quite marked. Greater deposits resulted at the lower temperatures, the difference in this particular test being about 38 per cent.

While the results of these tests are not surprising to engineers, who, in fact, anticipated them, they are not appreciated by car owners. Until it is possible for the engine designer to control oil consumption at a reasonable figure, I believe that a more definite effort should be made by the automobile makers and the oil companies to explain to car owners the causes of high oil consumption and the futility of using extremely heavy oil to control it. The results would be less engine carbon, better gasoline consumption, lower oil temperatures and far better lubrication.

Should Narrow Range of Operating Temperature

WALTER E. LEE[22]:—In stressing the cold-starting characteristics of motor oils, some oil companies have played up this one phase of engine lubrication because the motorist can distinctly recognize it as being a property of an engine lubricant. Although one oil may carbonize his engine badly at 4000 miles while another oil will go 10,000 miles for a similar engine condition, this difference goes unnoticed, and when his engine is too stiff to turn over on a cold morning he damns the oil and will buy no more of it.

The motorist seemingly is not interested in exceptional operation under normal conditions but becomes much exercised and voluble over the lack of good operation under abnormal conditions.

Although incidentally shown on Fig. 3 by Mr. Mougey, I wish to emphasize running in as an engine factor affecting oil consumption. When an engine is first run in with an oil of sufficiently light body having enough penetrability to assure good lubrication of tight pistons and rings, the initial oil consumption may be quite high, but the car can be operated for a considerable mileage without the consumption rate increasing materially.

We recently completed a test of two cars of the same make and having consecutive engine numbers, charging each with the same S.A.E. 20 oil. Each was driven 20,000 miles under identical conditions. By mere chance the first car started out using 1 qt. of oil to every 600 miles of operation, while the other car used 1 qt. to every 2000 miles. However, at the end of 20,000 miles, the first car was still getting 600 miles to the quart, but the second was using 1 qt. for every 350 miles. Incidentally, the engine in the first car was in perfect condition, whereas the second engine had developed a distinct piston slap in several cylinders.

The development of oil-temperature regulators to narrow the oil operating-temperature range in both summer and winter will go a long way toward improving engine lubrication and overcoming the bugbear of extreme viscosity in cold-starting and cold lubrication. When this shall have been accomplished, the oil refiner can exploit the true qualities of his oil: their lubricating value, their freedom from carbon-deposition tendencies, their stability against oxidation and so forth. The motorist can then judge the oil he buys on its merits under normal operating conditions and not under abnormal conditions such as prevail at present.

Engine Variables Have Most Effect

J. C. GENIESSE[23]:—To obtain more concrete information on the subject of oil consumption, we made block tests with a six-cylinder passenger-car engine and a four-cylinder truck engine. The data obtained showed that engine variables, such as speed, timing of valves and ignition and condition of rings, had far greater effect on oil consumption than had the properties of the oil. By varying any one of the engine conditions the oil consumption could be varied fourfold, whereas a variation of the viscosity of the oil from S.A.E. 20 to 40 and a change in the source of the oil from Gulf Coast to Pennsylvania crude did not change the consumption by more than 25 or 30 per cent. These tests clearly showed that the difficulty of running check oil-consumption tests undoubtedly is due to the sensitivity of the tests to slight mechanical variations in the engine.

In the belief that block tests do not tell the whole story as the customer views it, about 25 privately owned passenger-cars were placed under observation at a time of the year selected to include the summer week-end trips to seashore and mountain resorts. The drivers had no knowledge of the particular oils in the crankcases of their engines and were requested to drive normally. These tests checked the block tests in that they showed variations of only about 25 per cent between the worst and best oil. The most interesting information obtained was the fact that cars of different manufacture but of approximately the same age and driven at about the same speeds showed variations as high as tenfold in the rate of consumption.

Of the various oil properties that affect consumption, viscosity probably is the most important. However, since the viscosity limits are roughtly set by the engine manufacturer, the refiner has little control over this property. As Mr. Mougey has pointed out, even

[22] Head of fuel and lubrication section, Standard Oil Development Co., Research Laboratories, Elizabeth, N. J.

[23] M.S.A.E.—Research chemical engineer, Atlantic Refining Co., Philadelphia.

the variations possible by the choice of lubricants of different type are very limited. Over a range of 100 deg. fahr. the maximum variation possible is equivalent to only 15 deg. fahr. It may safely be stated that many engine manufacturers have in their hands far greater possibilities of controlling oil consumption than is held by the refiner.

SYDNEY BEVIN[24]:—I have always differed with Mr. Mougey regarding the amount of lubricating oil that is lost because of blow-by past the pistons sweeping the atomized oil out of the crankcase through breathers, filters or vents. Mr. Mougey holds that this does not account for a significant percentage of the total oil consumption. If there is any blow-by, it seems to me that the suction of the rush of the car through the air, which Mr. Mougey mentions, will sweep out of the crankcase a considerable quantity of atomized oil. A mental picture which I draw is of a room full of dust particles, with windows open on opposite sides. Certainly a draft through the room will carry out some of the dust particles.

RALPH R. TEETOR[25]:—Mr. Mougey's statement that the mechanical ill effects of oil-pumping, such as fouled spark-plugs, carbon deposits and valve trouble, had been overcome is very true. However, one effect, which has been only partly offset through the use of an oil-filter, is of sufficient importance that it should be added to his list. It is well known that in any engine which is subject to oil-pumping the lubricating oil stored in the sump is rapidly loaded with a residue of carbon and other foreign substances. The quantity of such deposit over a given period of time seems to be about in direct proportion to the quantity of oil that is dissipated past the pistons.

The only explanation found, so far, for such a condition is that, in the case of the oil-pumping engine, a greater quantity of oil remains on the cylinder-walls in the combustion-chamber above the piston and is carbonized at the time of combustion. A portion of such carbonized oil remaining on the cylinder is carried down past the pistons exactly as the oil found its way up past them and is finally scraped into the crankcase. Such carbon and foreign substances deposited in the crankcase rapidly pollute the oil with non-lubricating material, and the result is rapid wear of all parts of the engine.

These facts reverse the more or less popular opinion that the pistons and cylinders in an oil-pumping engine are always well lubricated. The fact is that the lubrication of an engine in which the oil consumption is well regulated is much better than in the oil-pumper. Therefore I believe that oil changes should be made much more frequently in the engine that is subject to high oil-consumption than in the engine in which the oil consumption is well regulated.

Results of Cold-Starting and Consumption Tests

C. M. LARSON[26].—Motor oil in a crankcase is often subjected to zero or sub-zero-weather exposure for 6 hr. or more at a stretch while parking in the open in winter months, yet it is invariably called upon to lubricate the engine when the car is driven at 50 to 60 m.p.h. over a stretch of 100 miles or more. To determine what is required of a motor oil to meet this situation, cold-weather operation and high-speed driving conditions were investigated, using motor-cars of numerous types. In this investigation the characteristics evaluated for motor oils of various types were (*a*) starting performance (cranking speed), (*b*) oil circulation (pumpability), (*c*) oil consumption and (*d*) stability (resistance to heat and sludging).

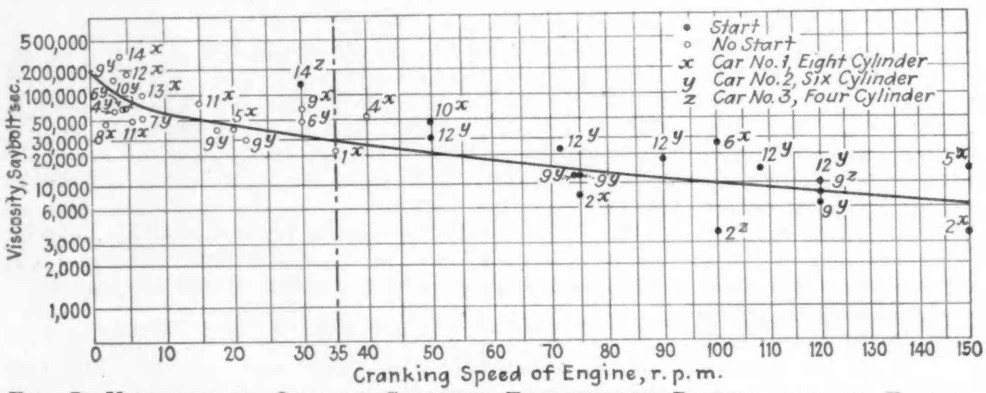

FIG. 7—VISCOSITY OF OILS AT STARTING TEMPERATURE PLOTTED AGAINST ENGINE CRANKING-SPEED

When the Viscosity Reached 175,000 Sec. the Oil Became So Adhesive that the Starter Motor Could Not Overcome the Oil-Film Resistance. As the Viscosity Become Lower, the Cranking Speed Increased. At a Viscosity of 30,000 Sec., a Cranking Speed of 35 R.P.M. Was Obtained, and the Engine Would Start at any Viscosity Below This

Starting tests were made during the winter of 1929-1930 with cars of three prominent makes, using five Texas-base, three Mid-Continent paraffin-base, three Pennsylvania paraffin-base and three miscellaneous motor oils, over a temperature range of -20 deg to $+40$ deg. fahr.

From the starting-test data, it was possible, as shown in Fig. 7, to plot the viscosity of each oil at the starting temperature against the cranking speed. The fact will be noted that, when the oil reached 175,000 sec. viscosity, it became so adhesive that the starter motor could not overcome the resistance set up by the oil film. As the viscosity became lower, the cranking speeds increased, with the result that, at 30,000 sec. viscosity, 35 r.p.m. was obtained and the engine would start at any viscosity below this. The oil in each test was not diluted by use. Subsequent runs proved that, had the engine been run for 20 miles or more after the crankcase was filled with new oil, 50,000-sec. viscosity would have been the highest for the oil before dilution to make starting possible afterward. It is of interest that the viscosity created by wax or petroleum jelly does not affect hard starting. High-pour-test oils were evaluated according to the straight-line viscosity-temperature curve rather than according to the higher viscosities existing below their pour-points.

[24] M.S.A.E.—Manager, sales engineering department, Tide Water Oil Co., New York City.

[25] M.S.A.E.—First vice-president, in charge of engineering, Perfect Circle Co., Hagerstown, Ind.

[26] M.S.A.E.—Supervising engineer, Sinclair Refining Co., New York City.

It was also found that, when a stop is made by using the choke, the engine can be started when using an oil one S.A.E. viscosity number heavier, because raw gasoline dilutes the oil film on the cylinder-walls and reduces the viscosity, thus making higher cranking-speeds possible.

To secure a more direct comparison of the different motor oils made from the several base crudes, starting tests were run on a sleeve-valve engine set up in a cold-room. The procedure was much the same as that followed in running the tests in the cars, except that, in addition to noting the cranking speeds with each of the oils at the various temperatures, the horsepower used to turn the engine over at a given speed was recorded. In Fig. 8 is plotted the horsepower required at different viscosities for two Texas-base, two Mid-Continent-base and one Pennsylvania-base oil. If 30 r.p.m. be taken as the cranking speed necessary to start a sleeve-valve engine 2.2 hp. is required at this speed, then the maximum viscosity of an oil for use in this type of engine should be set at 18,000 Saybolt sec.

Dewaxing Increases Oil Pumpability

Oil circulation, or pumpability, at low temperatures was checked on a 1930 Model-A-Ford pump assembly. Five different oils were used in this test. The results obtained, in gallons-per-minute discharge for various temperatures, are plotted in Fig. 9. The solid lines represent the rate of circulation above the pour-point of the oil; the dash lines, that below the pour-point. It will be noted that the dewaxed zero-pour-test Mid-Continent-base oil, S.A.E. 20, circulated at a better rate than the partly dewaxed Mid-Continent-base oil, S.A.E. 10. The dewaxed zero-pour Pennsylvania-base oil, S.A.E. 20, has pumpability, down to its pour-point, equal to that of the Texas-base oil, S.A.E. 10. This is because, for the same temperature, the latter oil is more sluggish and adhesive owing to its higher viscosity at the lower temperatures.

From the foregoing, it will be clearly seen that oils circulate below their pour-point. However, the rate of circulation is affected by both the viscosity of the oil at the time of test and the quantity and nature of the wax in the oil. This is brought out more clearly by Fig. 10, which is a plot of viscosity versus gallons discharged.

Relation of Consumption to Viscosity and Speed

Tests of oil consumption for different rates of speed were run in different parts of the Country with four different cars: Car *X*, the same one used in the starting tests; Cars *A* and A_1 six-cylinder cars of the same make; and Car *B*, a front-drive car. The cars were run over 100-mile stretches at average speeds of 30, 40 and 50 m.p.h., using each oil of several different series of oils. Each series consisted of S.A.E. Nos. 20, 30, 40 and 50 of the same make and crude.

After thoroughly flushing the engine, fresh oil was weighed in for each 100-mile run, and after the run it was drained and weighed for calculating the consumption. Samples of both the new oil and the used oil at the end of each 100-mile run were taken for analysis. From the log sheet shown in Fig. 11 it will be noted that, in addition to circulating-oil temperature readings, the viscosity of the oil in circulation was recorded by the automatic viscosimeter, shown in Fig. 12. Fig. 13 shows how the viscosities at the various speeds reach a stable point after about 50 miles. Fig. 14 is a graph showing the atmospheric temperature, the stable viscosity reached after the 50-mile run, the stable operating-temperature of the oil and the miles per quart, all of which are made for the three 100-mile runs at speeds of 30, 40, and 50 m.p.h. This set of runs was selected to show that the oils follow a definite trend as long as the atmospheric temperature does not affect the circulating-oil temperature. This was not the case with the runs made on the Pennsylvania-base oil, S.A.E. 50, in which set the atmospheric temperature was highest at the time of the 30-m.p.h. run but lower at the time of the 50-m.p.h. run than the average atmospheric temperature at the time the equivalent runs were made on the S.A.E. Nos. 30 and 40 oils. This resulted in the warm weather causing the stable viscosity as well as the miles per quart at 30 m.p.h. to be lower with the S.A.E. 50 than with the lighter oils at the corresponding speed. However, the rest of the curve is nearly normal. This same trend was recorded in other runs with the other cars and with different series of motor oils.

To make possible a consistent comparison between the different grades of the many series of motor oils used,

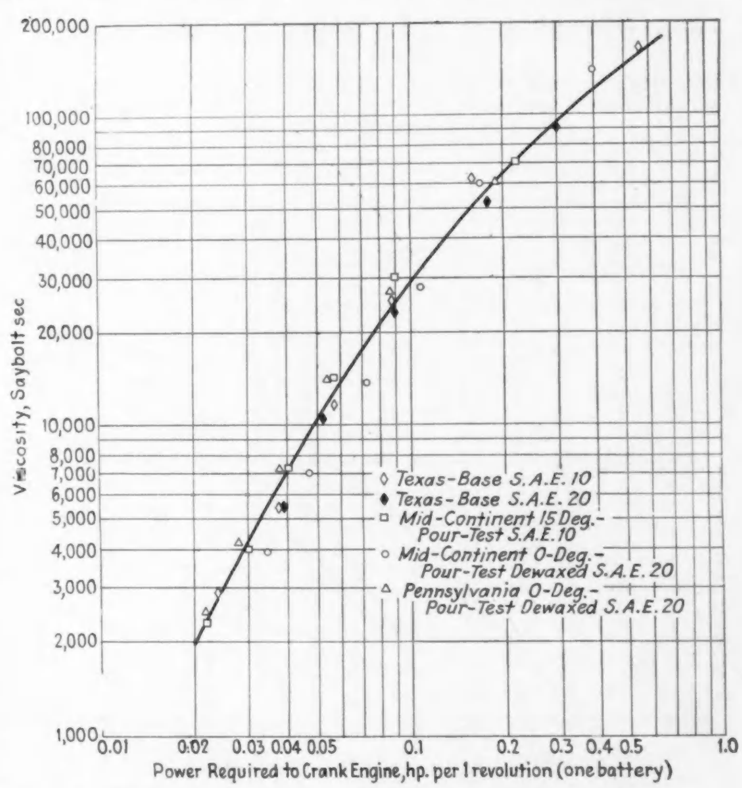

FIG. 8—POWER REQUIRED TO CRANK SLEEVE-VALVE ENGINE AT STARTING SPEED AT DIFFERENT VISCOSITIES, USING VARIOUS MOTOR OILS

it was necessary to plot the miles per quart for the different average rates of speed against the actual stable viscosities at the operating temperature of the circulating oil, rather than to use the viscosities at 100, 130 or 210 deg. fahr. Fig. 15 shows that the mileage per quart of oil bears a direct relation to the stable operating viscosity and that the higher the average rate of speeds is, the greater is the oil consumption per 100 miles.

Differences in make or design of engine also change this oil-consumption curve for the same stable operating-temperature. It is worth noting that, when the stable operating-viscosity drops to 50 Saybolt sec. or lower, the rate of speed has very little effect on oil consumption and that the mileage per quart is very unsatisfactory. It is also noteworthy that the cars showing the higher mileages consumed considerably more oil than those showing 10,000 to 12,000 miles on the odometer in cases where the same oil was used.

To demonstrate the lasting qualities of the oil at various rates of speed, two series of oils of S.A.E. Nos. 20 and 30, made from the different base crudes, were selected. Fig. 16 shows the miles per quart obtained from each. It will be seen that, throughout the full range of sustained driving speeds of 30, 40 and 50 m.p.h., the Pennsylvania paraffin-base dewaxed oils show the greatest number of miles per quart over each of the 100-mile runs. This is confirmed by the Cadillac evaporation test on the new oils and goes to prove that Pennsylvania paraffin-base dewaxed oils, grade for grade, assure the least consumption.

With a view to determining how motor oils are affected by sludging, a series of three runs of 100 miles

OIL USED Zero Pour S.A.E. 30 (Penna) DATE Oct. 22 & 23 1930

MPH	TIME	MILES	EXACT LUBRIMETER READING	TEMPERATURE ATMOSPHERE	TEMPERATURE OIL		Lb.	Oz.	REMARKS: All tests run on U.S. #71, starting 15 miles south of K.C. and going 50 miles and returning
30	9:00	Start Motor	800	43	80	Motor Oil	lb.	oz.	This test was run Oct. 22, 1930 in the rain.
	9:00	Start Run	800	43	80	Initial Fill	10	7	The Oil temperature taken from unit in oil lines to Lubrimeter and bearings.
	9:06	Out of White	440	43	97	Oil added			Only stop at turn-a-round point.
						Oil drained	10	6+	
	9:00	0	800	43	80	Percent Dilution			
	9:19	10	260	43	117	Oil Used		1-	
	9:40	20	240	43	120	Miles per Quart			
	10:00	30	240	43	120	3800			
	10:20	40	225	45	122				
	10:40	50	225	45	122	Gasoline			
	11:00	60	215	45	124	Brand			
	11:20	70	215	45	124	Initial Fill			
	11:40	80	215	45	124	Added			
	12:00	90	215	45	124	Miles per Gallon			
A	12:20	100	215	45	124				
40	9:00	Start Motor	800	43	80	Motor Oil	lb.	oz.	This test was run Oct. 23, 1930 — Fair weather with North Wind.
	9:00	Start Run	800	43	80	Initial Fill	10	12	Other conditions same as above.
	9:04	Out of White	440	43	97	Oil added			
						Oil drained	10	6+	
	9:00	0	800	43	80	Percent Dilution			
	9:15	10	190	44	130	Oil Used		6-	
	9:30	20	170	45	135	Miles per Quart			
	9:45	30	150	47	140	560			
	10:01	40	150	49	140				
	10:15	50	140	49	145	Gasoline			
	10:30	60	140	49	145	Brand			
	10:45	70	140	49	145	Initial Fill			
	11:00	80	140	49	145	Added			
	11:16	90	140	49	145	Miles per Gallon			
B	11:30	100	140	49	145				
50	1:00	Start Motor	800	53	80	Motor Oil	lb.	oz.	Same day as Test "B" with same general conditions as remarked above.
	1:00	Start Run	800	53	80	Initial Fill	10	14	
	1:02½	Out of White	440	53	97	Oil added			
						Oil drained	10	0	
	1:00	0	800	53	80	Percent Dilution			
	1:12	10	130	53	150	Oil Used		14	
	1:24	20	100	53	165	Miles per Quart			
	1:36	30	100	54	165	230			
	1:48	40	98	54	166				
	2:00	50	96	54	167	Gasoline			
	2:12	60	95	54	167	Brand			
	2:24	70	95	54	167	Initial Fill			
	2:36	80	95	54	167	Added			
	2:48	90	95	54	167	Miles per Gallon			
C	3:00	100	95	54	167				

Car "A" (23000 Miles on this car – No piston work.)

Owner or Firm Test for CML C.W. McAllister Staff Engineer

FIG. 11—LOG SHEET OF CAR *A* RUN IN OIL-CONSUMPTION TEST

Note that the Viscosity of the Oil as Recorded by the Lubrimeter, or Automatic Viscosimeter, Is Given as Well as the Atmospheric and Circulating-Oil Temperatures

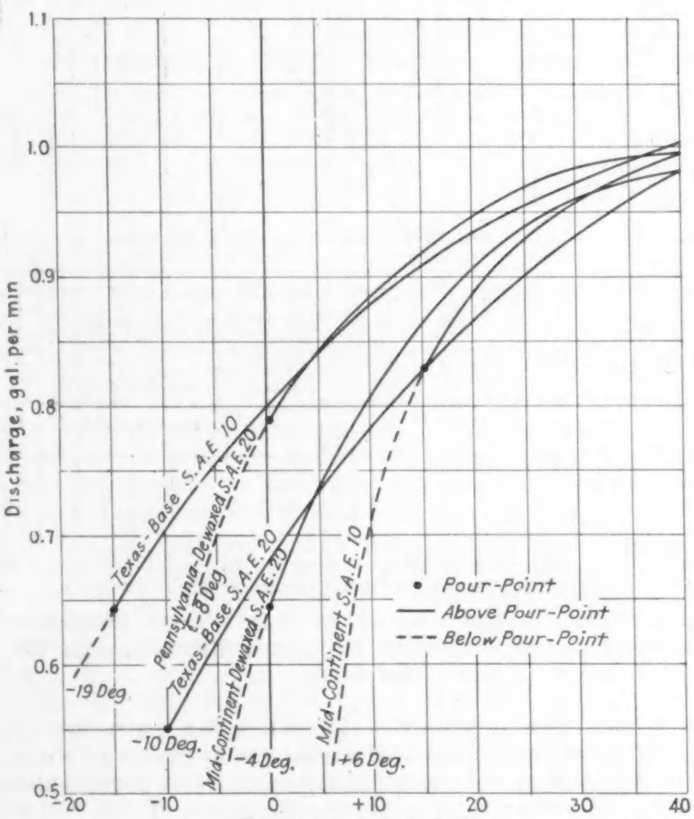

FIG. 9—OIL DISCHARGE RATE OF MODEL-A FORD PUMP AT DIFFERENT TEMPERATURES

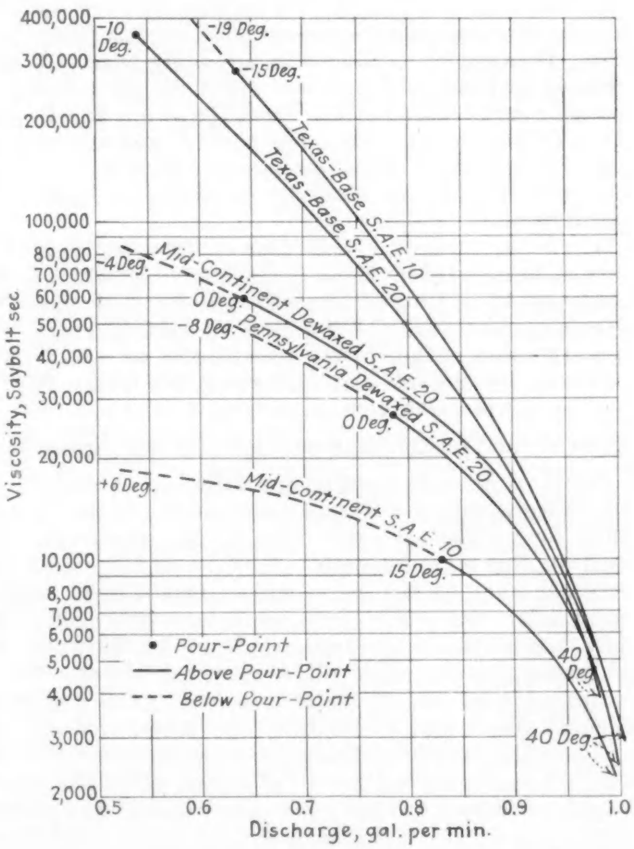

FIG. 10—EFFECT OF VISCOSITY AND WAX ON PUMPABILITY OF OILS

The Rate of Discharge Is Affected by Both the Viscosity of the Oil and the Quantity and Nature of the Wax in the Oil

each was undertaken, one run averaging 30 m.p.h., a second 40 m.p.h. and a third 50 m.p.h. The crankcase of Car *X* was filled for each run with new high-grade filtered motor oil, S.A.E. 40, and complete crankcase drainings were made at the end of the runs. The increase in sediment for the three rates of speed is shown in Fig. 17.

One Versus Three Viscosity Grades

Some automobile manufacturers' instruction books give three S.A.E. viscosity numbers as a guide to the

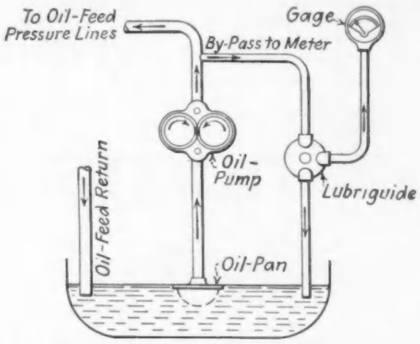

FIG. 12—DIAGRAMMATIC SKETCH OF AUTOMATIC VISCOSIMETER

are used. This is clearly brought out in Fig. 18, in which the Texas-base oils are plotted against dewaxed Mid-Continent and Pennsylvania-base motor oils on the Sinclair viscosity-temperature chart.

Starting with a temperature of −20 deg. fahr. and using a Texas-base oil, S.A.E. 10, shown by the dash line at *A*, the viscosity decreased to *B* (0 deg. fahr.), which atmospheric temperature it would be necessary to change over to S.A.E. 20, raising the viscosity at 0 deg. fahr. to *C*. From *C* the viscosity

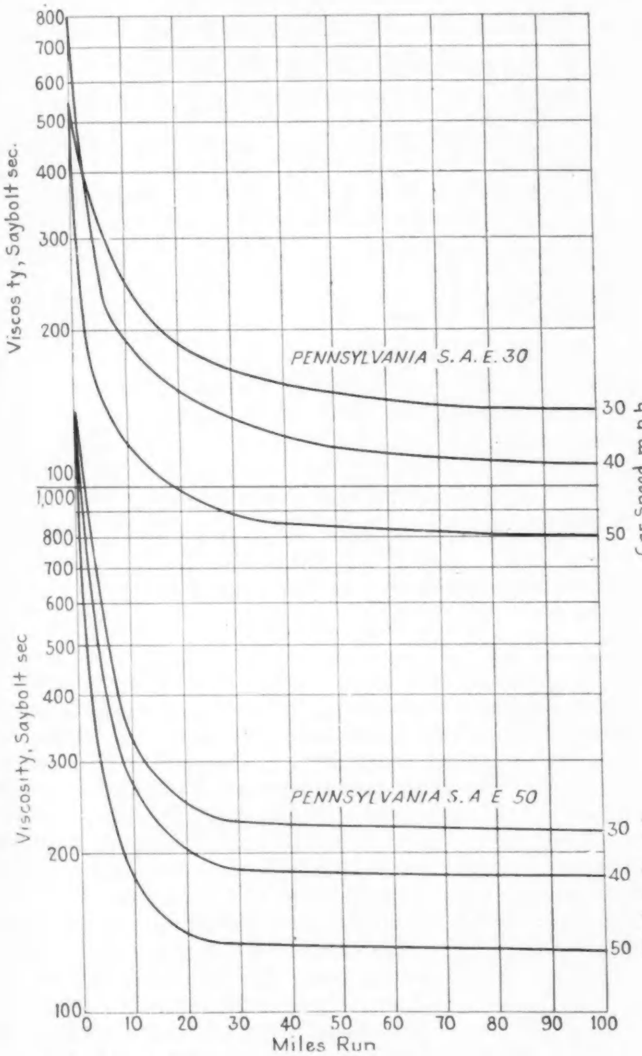

FIG. 13—DECREASE OF VISCOSITY WITH OPERATION

Note that After about 50 Miles the Viscosity Reaches a Condition of Stability at the Several Car-Speeds

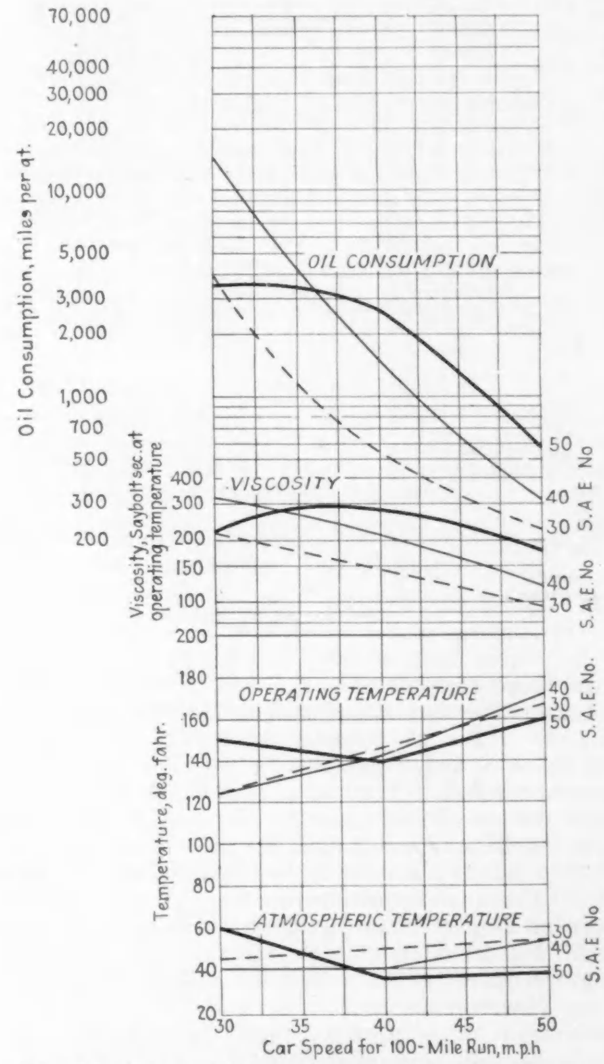

FIG. 14—GRAPH OF TESTS RUN IN CAR *A* ON PENNSYLVANIA-BASE OILS, SHOWING ATMOSPHERIC TEMPERATURE, STABLE VISCOSITY REACHED AFTER 50-MILE RUN, STABLE OPERATING-TEMPERATURE OF THE OIL AND RATE OF OIL CONSUMPTION AT THREE CAR-SPEEDS

selection of oils of the correct body or viscosity for summer and winter lubrication, as follows: for summer, S.A.E. No. 30; for winter, down to 0 deg. fahr., S.A.E. No. 20; below 0 deg fahr., S.A.E. No. 10.

Since these S.A.E. numbers are intended to apply to oils of all types, including oil that thins out the most at high temperatures and thickens most at low temperature, more grades are necessary for a wide range of temperature than are needed when paraffin-base oils

drops to *D* (32 deg. fahr.), where the use of S.A.E. 30 is recommended. This raises the viscosity to *E*. Since S.A.E. No. 30 is used for summer, the viscosity of this oil drops to some point between F_1 and F_2 due to the heat of the engine in operation. This series shows the general trend of the temperature-viscosity slope of the

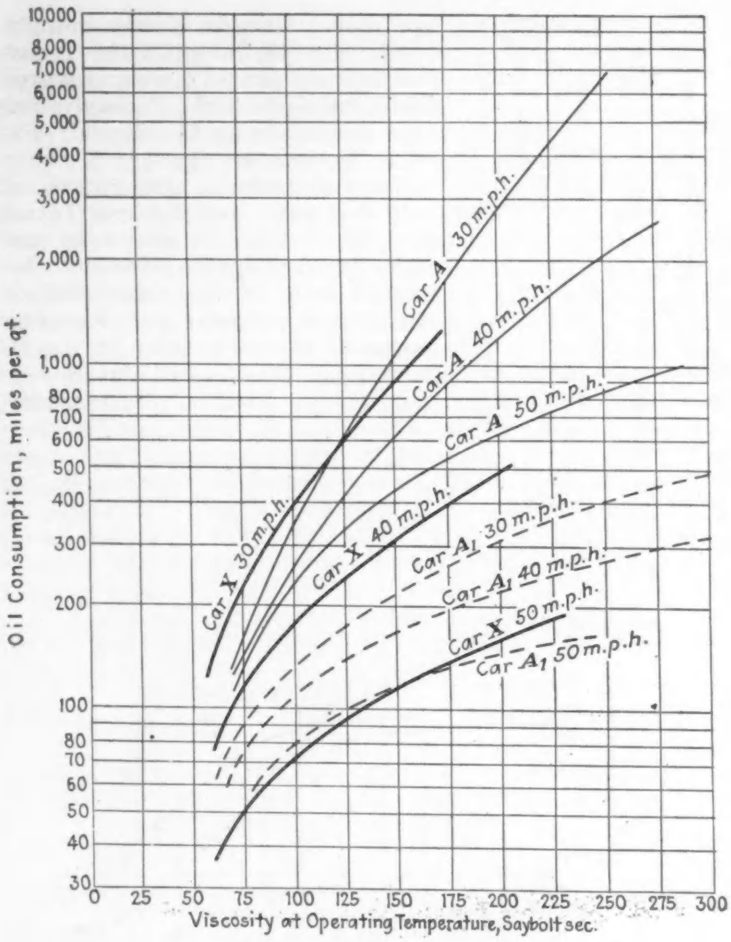

FIG. 15—RELATION OF OIL CONSUMPTION TO STABLE OPERATING-VISCOSITY AND AVERAGE CAR-SPEED

Pennsylvania-Base Motor Oils Were Used in the Test Runs. Car A_1 Was Run 68,000 Miles

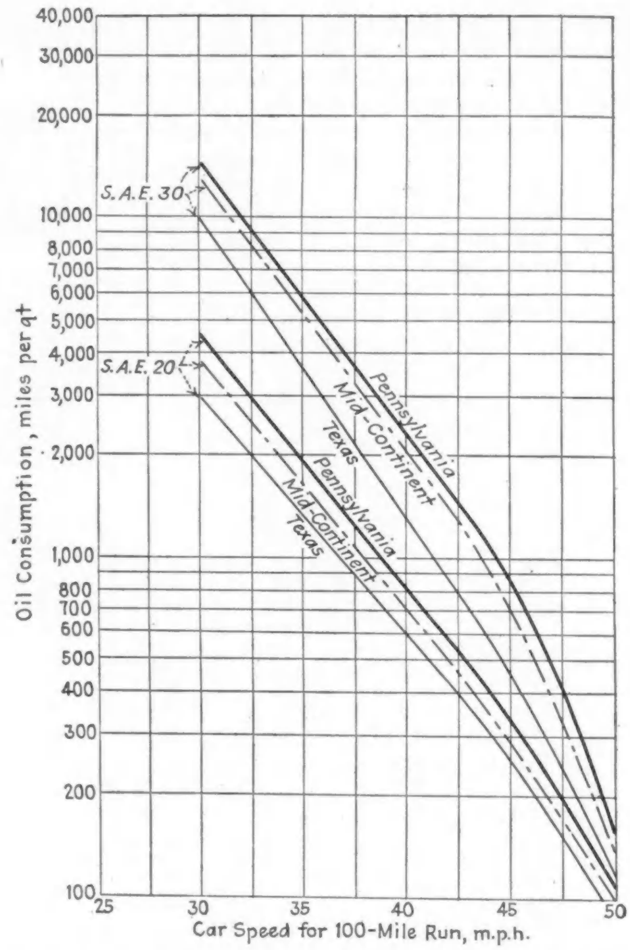

FIG. 16—EFFECT OF SPEED ON LASTING QUALITY OF OILS

The Highest Mileage per Quart throughout the Full Range of Driving Speeds for the 100-Mile Runs Was Shown by the Pennsylvania Paraffin-Base Dewaxed Oils. The Tests Were Run in Car *Y*, Operated 33,400 Miles

three Texas-base motor oils, S.A.E. Nos. 10, 20 and 30.

Against this is plotted in solid lines the temperature-viscosity curve of dewaxed zero-pour Mid-Continent paraffin-base and Pennsylvania paraffin-base dewaxed zero-pour S.A.E. No. 30 oils. This shows that the last-named motor oil maintains its viscosity or body better than the Texas-base S.A.E. 30 at high temperatures yet does not thicken nearly so much as the Texas-base S.A.E. No. 10 at low temperatures. Therefore the one grade of Pennsylvania paraffin-base dewaxed zero-pour S.A.E. No. 30 oil is suitable for the full temperature-range of operation for which the automobile manufacturers' instruction books recommend three grades of oil. The Mid-Continent paraffin-base zero-pour motor oil gives virtually the same results.

In Fig. 18, at 50,000 Saybolt sec. viscosity, is drawn a horizontal dot-dash line above which is the zone of hard starting. The basis for determining this limit is shown in Fig. 7. At 60-sec. viscosity is drawn a similar line below which the oil is too thin for safe operation.

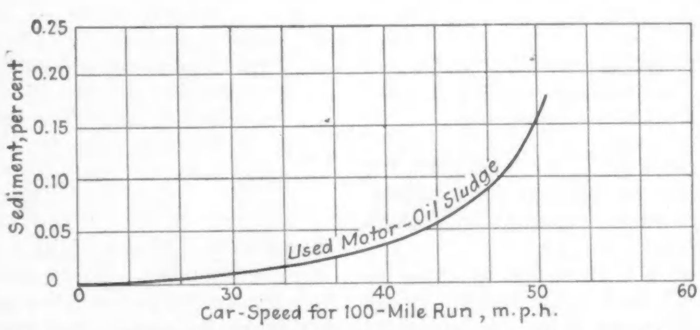

FIG. 17—INCREASE OF SEDIMENT IN MOTOR OIL WITH INCREASED CAR-SPEED

Steam-turbine bearings perform most satisfactorily with an oil having a viscosity of 60 sec. at operating temperature. The lubrication arrangement of turbine bearings is regarded as most excellent, the journals virtually floating on an oil film that is made as free from contamination as is possible by the use of filtering systems. Tests on the spindles of cotton textile mills show that iron is present when the viscosity of the lubricating oil at operating temperatures reaches less than 50 sec.; yet, when the viscosity is higher than 70 sec., power is lost due to drag. By referring to Fig. 15, it will be noted that, regardless of the speed, the mileage per quart of oils is very unsatisfactory as it approaches 50 Saybolt sec. viscosity at engine-operating temperatures.

The use of three grades of oil is impractical, because the weather conditions in certain localities, where the temperature fluctuates between 0 and 40 deg. fahr. overnight,

(*Concluded on page* 231)

Factors Controlling Engine-Carbon Formation

By W. H. Bahlke[1], D. P. Barnard[2], J. O. Eisinger[2], and O. FitzSimons[1]

Chicago Section Paper

THE Conradson carbon-residue test is the generally accepted method for predicting the relative quantities of carbon an oil will deposit in an engine. This belief arises from the fact that, although publication of results of earlier researches in this field have shown that volatility of the oil is a controlling factor, it has been assumed that in all cases volatility is measured by the carbon-residue test. The results of tests conducted by the authors, covering a period of about two years, show that no such general relationship exists when the carbon-forming characteristics of a wide variety of oils are considered. This conclusion is drawn from 50-hr. tests of a large number of commercial lubricating oils in an engine operating under fairly heavy load and at moderate speed.

The authors found that the volatility of the oil is the primary factor in engine carbon-deposition, and a laboratory method was developed for indicating the total volatility of a motor oil. The temperature of the 90-per-cent-distilled point at an absolute pressure represented by 1 mm. of mercury was found to be an excellent *carbonization index*, because a linear relation was found between this temperature and the quantity of carbon deposited. Other data showing the effect on carbon deposition of oil consumption, load, and length of time of operation are presented.

THE GREAT AMOUNT of necessary labor involved in any experimental work dealing with combustion-chamber carbon-formation is in all probability chiefly responsible for the paucity of published reports of research work on this subject. Further, through the use of improved temperature regulation, piston-ring design and the like, the engine designer has minimized carbon formation markedly as compared with that of former days. But combustion-chamber carbon seems to offer a very definite obstacle to the use of appreciably increased compression-ratios, and this paper is presented to show the effects on carbon deposition which can be realized by changes in the character of the lubricating oil.

The Conradson carbon-residue value of an oil has generally been assumed to measure its carbonizing tendency, although the fact that the rate of formation of carbon in the combustion-chamber of the internal-combustion engine is probably strongly influenced by the volatility of the oil has long been recognized. Nearly 10 years ago Prof. W. K. Lewis pointed out the advantages of oils of high total volatility in this respect, in a lecture at the Massachusetts Institute of Technology. The idea was frequently repeated later in a course given by one of the authors at the Institute. The first published work on this phase of the subject appears to be that of Gruse[3] and his co-workers, who have subsequently expanded their work to include a system of road tests[4] on a fleet of motorcoaches powered with sleeve-valve engines. Recently, an article by Thornycroft and Barton[5] still further emphasizes the low carbon-forming properties of oils which can be completely evaporated at comparatively low temperatures.

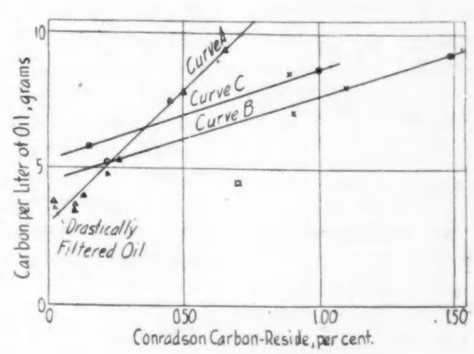

FIG. 1—RELATION BETWEEN COMBUSTION-CHAMBER CARBON AND CONRADSON CARBON-RESIDUE AS DETERMINED BY LIVINGSTON, MARTIN AND MARLEY[4]

Gruse has concluded that the Conradson carbon-residue value of an oil is a measure of its total volatility and, therefore, can be regarded as indicative of the tendency of the oil to produce combustion-chamber carbon. Fig. 1 was reproduced from this work, the different curves representing series of tests conducted under varying conditions. So far as the authors are aware, the use of the 90-per-cent-evaporated point in a simple distillation at reduced pressure as a measure of the tendency of an oil to form combustion-chamber carbon was first suggested by one of the authors early in 1928. The most recent contributions of Gruse's co-workers also include this suggestion, although they evidently still regard the Conradson carbon-residue value as a satisfactory criterion, at least insofar as poppet-valve engines are concerned.

This problem has been made the subject of intensive study by the authors. The following data were taken from an experimental investigation which has been in

[1] Research laboratory, Standard Oil Co. (Indiana), Whiting, Ind.

[2] M.S.A.E.—Research laboratory, Standard Oil Co. (Indiana), Whiting, Ind.

[3] See *Journal of Industrial and Engineering Chemistry*, May, 1926, p. 502; see also THE JOURNAL, June, 1926, p. 607, and June, 1927, p. 688.

[4] See *Journal of Industrial and Engineering Chemistry*, October, 1929, p. 904; see also THE JOURNAL, November, 1929, p. 489.

[5] See *Aircraft Engineering*, vol. 2, 1930, p. 36; see also *Journal of the Institution of Petroleum Technologists*, October, 1930, vol. 16, No. 84, p. 379-A.

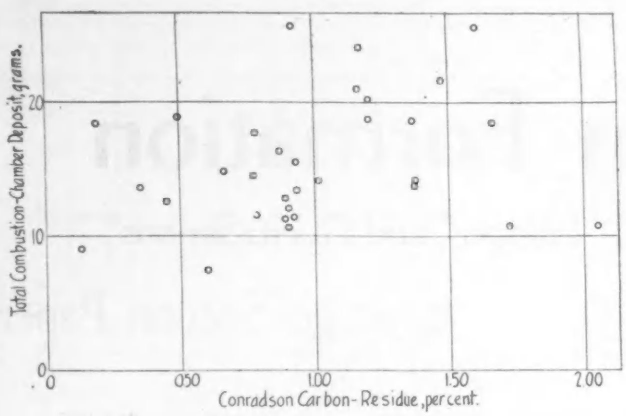

Fig. 2—Conradson Carbon-Residue and Combustion-Chamber Deposit Compared

The Lack of Agreement between the Conradson Carbon-Residue of an Oil and Its Tendency To Deposit Carbon in an Engine Is Rather Definitely Shown. For Engine No. 1, the Jacket-Water-Outlet Temperature Was 175 Deg. Fahr., That of the Oil Being 170 Deg. Fahr. The Engine Load Was 55 to 65 Per Cent of the Maximum Power at 1700 R.P.M.

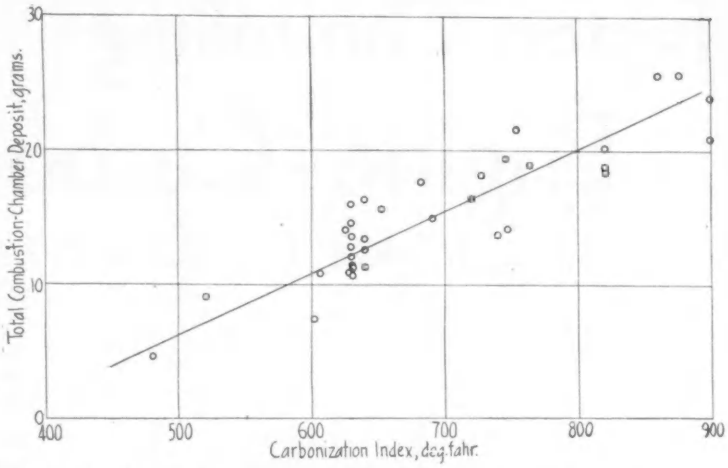

Fig. 3—Curve Showing Carbonization Index versus Total Combustion-Chamber Deposit

The Engine Conditions Were the Same as for Fig. 2. A Rather Good Relationship Exists between the Carbonization Indices of Oils as Measured by the Temperature at Which 90 Per Cent Is Evaporated under a Pressure of 1 Mm. of Mercury and the Combustion-Chamber Deposits of These Same Oils

progress for approximately three years. So far as possible, only that part of the work most intimately associated with carbon deposition will be considered herein.

Method of Investigation

The work was initiated with Engine No. 1, a 2 5/16 x 4⅜-in. six-cylinder sleeve-valve passenger-car type that developed 34 b.hp. at 1700 r.p.m. The engine was installed on a dynamometer test-stand and provided with a cooling-water jacket around the oil sump.

The entire set-up was conventional in every respect and at the outset 100-hr. runs were made. A few tests, however, indicated that concordant results could be obtained in much less time and accordingly the operating conditions listed in Table 1 under Engine No. 1 were adopted for the first series of tests.

Correlation of Observations

Correlation with the Conradson carbon-residue values was attempted with what at first seemed to be a fair degree of success; but, as more data were accumulated, it became apparent that not all of the discrepancies could be ascribed to unidentified engine variations. Fig. 2 shows all of the data obtained on Engine No. 1 in the first series of tests of a large number of commercial oils plotted on this basis, the lack of order being evident. Table 2 shows the characteristics of the oils used. Fig. 3 shows the same data when coordinated with the 90-per-cent-distilled temperature obtained by a standardized simple distillation at a pressure of 1 mm. of mercury. Distillation apparatus details and the methods used are stated on p. 220.

TABLE 1—ENGINE-DYNAMOMETER TESTS IN WHICH THE MIXTURE-RATIO AND THE SPARK WERE ADJUSTED FOR MAXIMUM POWER FOR ALL TESTS

	Engine No. 1	Engine No. 2
Length of Tests, hr.	50	50
Speed, r.p.m.	1,700	1,700
Load, b.hp.	18 to 20	34 to 36
Jacket-Water Outlet-Temperature, deg. fahr.	175	175
Oil Temperature, deg. fahr.	170	170

It appeared from this work that the temperature at which 90 per cent is evaporated under properly chosen conditions might be used as an index of the *total* volatility of the oil which, if the behavior indicated in Fig. 3 could be generally substantiated, would serve as a satisfactory indication, or *carbonization index*, of the tendency of the oil to form combustion-chamber carbon.

The first tests, already described, were therefore supplemented by a study in two engines of another series of oils selected with a view to testing further the suitability of the carbonization index as a criterion for carbon deposition. Engine No. 2 was of the overhead poppet-valve type having six 3¾ x 5-in. cylinders and developing 70 b.hp. at 1700 r.p.m. Engines Nos. 1 and 2 were operated on the dynamometer stand under the conditions described in Table 1. The oils used were chosen particularly to determine whether any property other than volatility might possibly affect the amount of carbon obtained. Thus, at a given volatility, oils of

TABLE 2—CHARACTERISTICS OF OILS USED IN THE FIRST SERIES OF TESTS; SEE FIGS. 2 AND 3

Oil No.	Gravity, A.P.I. Deg.	Flash Point, Deg. Fahr.	A.S.T.M. Pour Point, Deg. Fahr.	Viscosity, Saybolt Sec. 100 Deg. Fahr.	Viscosity, Saybolt Sec. 210 Deg. Fahr.	Carbon Residue, Per Cent	Carbonization Index, Deg. Fahr.
1	27.0	465	35	1,034	89	1.16	900
2	24.7	425	25	751	75	0.92	876
3	28.0	440	0	776	77	0.19	745
4	23.2	490	45	2,111	122	1.60	860
5	23.7	450	45	1,150	90	1.20	820
6	25.2	425	40	961	82	0.49	763
7	22.1	500	20	2,478	128	1.47	753
8	21.1	500	10	2,241	120	1.36	740
9	23.2	500	20	1,952	115	1.36	728
10	24.2	490	30	1,310	92	0.78	682
11	25.3	395	5	935	79	0.45	640
12	21.3	445	10	1,596	95	0.93	640
13	21.9	330	5	1,281	91	0.90	630
14	22.0	460	10	1,546	97	0.90	630
15	21.9	460	10	1,571	..	0.89	630
16	24.6	500	15	1,258	86	0.35	630
17	18.1	510	20	2,900	112	2.10	629
18	22.0	350	10	1,550	97	0.77	630
19	18.2	480	10	2,470	107	1.72	607
20	21.7	375	0	661	62	0.60	601
21	27.5	385	0	322	52	0.00	480
22	19.2	420	5	1,775	81	0.13	520

widely different behavior toward oxidation and toward carbon formation on severe cracking were chosen.

The oils are described in Table 3 and the distillation of these same oils under a pressure of 1 mm. of mercury are given in Fig. 4. A brief consideration will show the strikingly wide variations in their other properties in addition to total volatility. For example, oil *E* is an unrefined distillate, is very unstable and readily forms sludge under engine conditions. On the other hand, oils *D*, *A* and *H* are exceptionally stable as regards sludging. It should be noted also that oil *H* is a petrolatum wax of high melting-point—produced from bright stock —and although of a very high-boiling grade has a very low carbon-residue value. Oils *D* and *H* are much more severely refined than the usual commercial lubricating oil; in fact, they are refined sufficiently to make them substantially colorless, odorless and tasteless products. A wide range in viscosity is also covered.

With this series of oils the poor correlation of engine carbon with the Conradson value is again evident as in Fig. 5, but Fig. 6 shows fairly good agreement on the basis of carbonization index. In the foregoing work the exhaust-sleeve-port carbon was not included with the deposits from Engine No. 1 because of the apparent tendency of the port carbon to blow away when the

TABLE 3—CHARACTERISTICS OF OILS USED IN SECOND SERIES OF TESTS

Oil	Description	Gravity, A.P.I. Deg.	Flash Point, Deg. Fahr.	A.S.T.M. Pour Point, Deg. Fahr.	Viscosity, Saybolt Sec. 210 Deg. Fahr.	Viscosity, Saybolt Sec. 100 Deg. Fahr.	Carbon Residue, Per Cent	Color, N.P.A.	Carbonization Index, Deg. Fahr.
C	Regularly Refined Lubricating Oil	20.1	390	0	57	601	0.06	4 to 4½	496
D	Produced from Oil *C*, by Drastic Refining	27.3	395	—15	51	319	0.00	Water White	496
E	Unrefined Lubricating-Oil Distillate	18.2	505	5	112	2,607	2.03	Dark	630
F	Oil *E*, Acid Treated	20.9	480	5	96	1,758	1.01	8	630
A	Oil *F* Percolated Through Clay	21.3	485	5	92	1,663	0.90	3½	630
G	Blended by Moderate Acid Treatment but Highly Filtered	24.9	450	30	86	1,071	0.60	2½ to 3	820
H	Petrolatum Wax	. . .	485	. .	62	160 (melting point)	0.05	Water White	900

TABLE 4—CHARACTERISTICS OF OILS *A* AND *B*

Oil	Description	Gravity, A.P.I. Deg.	Flash Point, Deg. Fahr.	A.S.T.M. Pour Point, Deg. Fahr.	Viscosity, Saybolt Sec. 210 Deg. Fahr.	Viscosity, Saybolt Sec. 100 Deg. Fahr.	Carbon Residue, Per Cent	Color, N.P.A.	Carbonization Index, Deg. Fahr.
A	Refined Distillate Motor Oil	21.3	485	5	92	1,663	0.90	3½	630
B	Blended Motor Oil	23.3	375	30	92	968	1.20	7 to 8	820

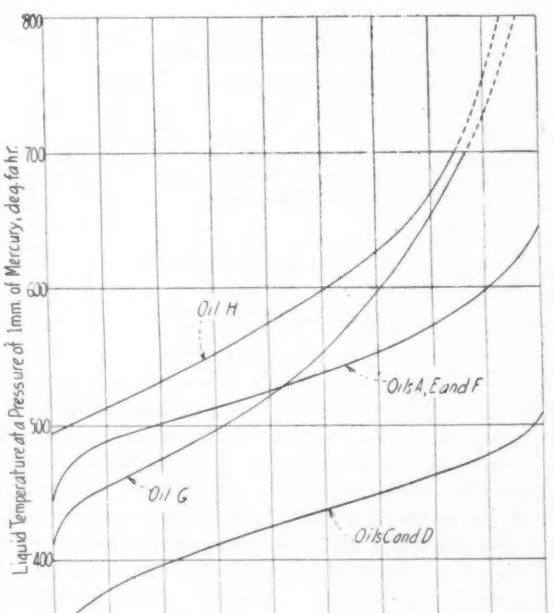

FIG. 4—TYPICAL DISTILLATION CURVES SHOWING THE DISTILLATIONS UNDER A PRESSURE OF 1 MM. OF MERCURY OF THE SPECIAL OILS USED IN THE SECOND SERIES OF TESTS

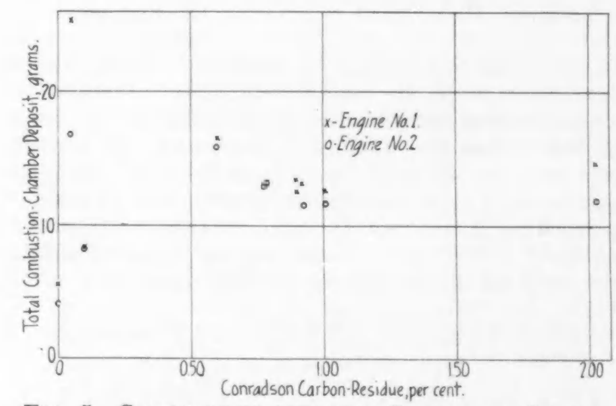

FIG. 5—COMPARISONS BETWEEN CONRADSON CARBON-RESIDUE AND COMBUSTION-CHAMBER DEPOSIT

The Lack of Agreement between the Conradson Carbon-Residue of Oils and Their Carbon Deposition in Two Types of Engine Is Clearly Shown. The Jacket-Water-Outlet Temperature Was 175 Deg. Fahr. and That of the Oil 170 Deg. Fahr. The Engine Load Was 60 Per Cent of the Maximum Power at 1700 R.P.M.

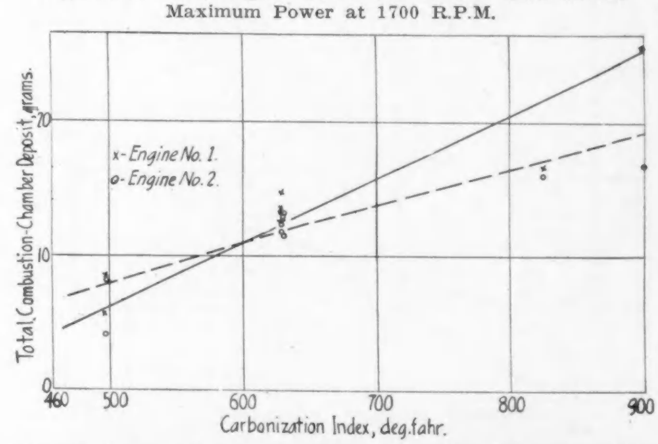

FIG. 6—CURVES SHOWING THE RELATION BETWEEN CARBONIZATION INDEX AND COMBUSTION-CHAMBER DEPOSIT

For the Two Engines of Radically Different Design a Good General Relationship between Oil Volatility and Engine Carbon Deposit Exists. The Engine Conditions Were the Same as for Fig. 5

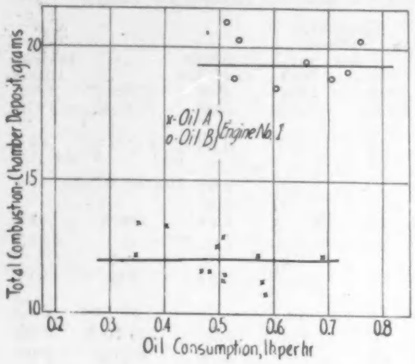

FIG. 7—SHOWING THE EFFECT OF A CHANGE IN OIL CONSUMPTION ON THE AMOUNT OF COMBUSTION-CHAMBER DEPOSIT

Over a Rather Wide Range in Oil Consumption No Marked Increase in the Carbon Deposit in Engine No. 1 Is Apparent. The Jacket-Water-Outlet Temperature Was 175 Deg. Fahr., and That of the Oil 170 Deg. Fahr. The Engine Load Was 55 to 65 Per Cent of the Maximum Power at 1700 R.P.M.

opening became seriously obstructed.

In all of their work Gruse and his associates have reported carbon deposits upon the basis of percentage of dry carbon in the amount of lubricating oil consumed by the engine. It is the belief of the authors that this method does not give a clear picture for practical purposes. Obviously, some allowance should be made for the presence of inorganic material drawn in with the intake air when it is definitely known that the dust content of the air varied considerably from test to test. Analyses of many carbon deposits indicate, however, that only a small quantity of foreign matter is ordinarily present in engines operated in the protected atmosphere of the laboratory, although fully half of the deposits in engines operated on the road may be "just dirt." Further, the heat-insulating effect of the carbon deposit is due largely to the deposit as a whole,

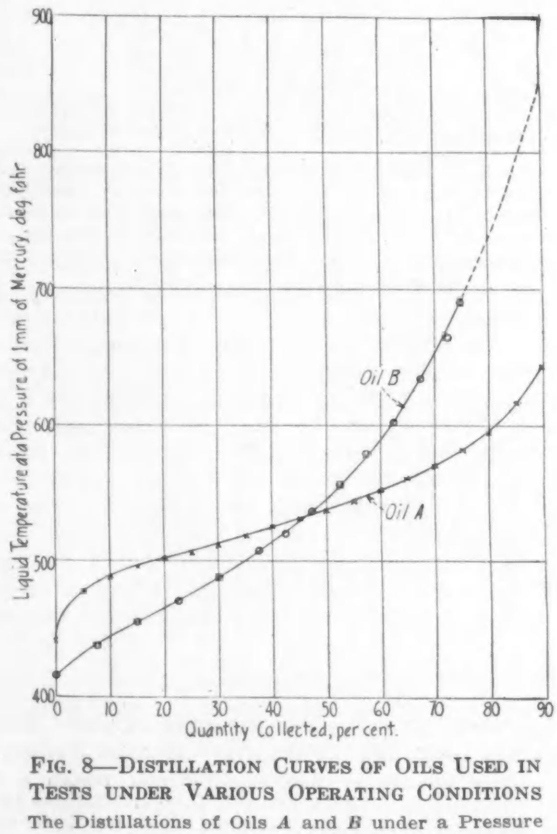

FIG. 8—DISTILLATION CURVES OF OILS USED IN TESTS UNDER VARIOUS OPERATING CONDITIONS

The Distillations of Oils *A* and *B* under a Pressure of 1 Mm. of Mercury Show the Marked Differences in the Upper-End Volatilities

and if one oil tends to give a "wet" deposit containing a considerable quantity of tarry matter it seems only fair to charge the presence of this material against the lubricant. In addition, the results reported by Gruse infer that, other things being equal, carbon deposition is proportional to oil consumption, although their data do not cover a sufficient range to prove this point. A consideration of the mechanism by which the deposit is formed, however, indicates that this is probably not the case.

Any carbon formed from the oil particles in the central portion of the combustion space probably passes on out through the exhaust valve, and the carbon actually deposited probably is formed on the surfaces themselves. So long as the surfaces are coated with an oil film of the maximum thickness that is capable of

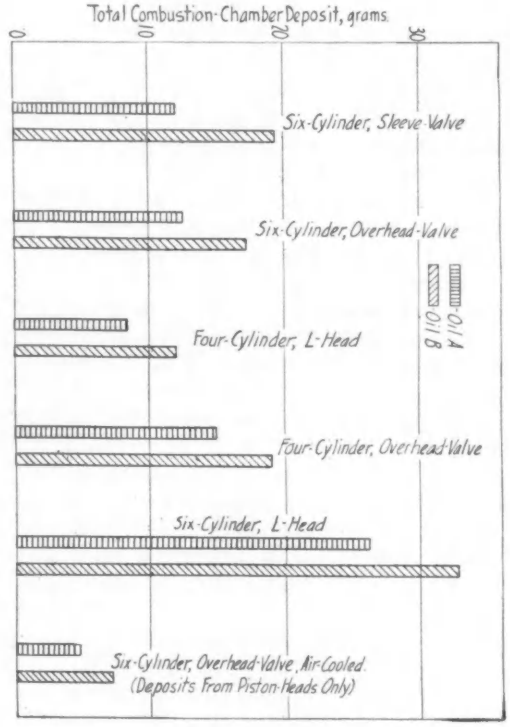

FIG. 9—A GRAPHICAL REPRESENTATION OF THE PERFORMANCE OF OILS *A* AND *B* IN VARIOUS TYPES OF ENGINE

remaining on the piston-head in the face of the reciprocating motion and on the cylinder-head against the scrubbing action of the gas, the rate of carbon deposition should be independent of the excess oil that cannot adhere to these surfaces. Further, too many opportunities for the escape of oil exist in any engine to justify the assumption of a general relation between carbon and consumption. Under *extreme conditions*, as has long been recognized, oil consumption will play a most important part in determining the amount and character of the deposit and, when the oil consumption of the engines under test became excessive, the engines were overhauled and new parts installed where needed. However, over the range of consumption usually deemed normal it apparently has little, if any, effect.

Fig. 7, for the sleeve-valve-type engine, gives a good idea of how carbon formation may be substantially independent of a fairly wide variation in oil consumption.

The characteristics of the two oils used in this and the following tests are given in Fig. 8 and Table 4. As the behavior of other engines employed in this work has been similar to that shown in Fig. 7, we feel that the procedure of correlating with the *total* carbon deposit as actually found is well justified.

A certain amount of additional data confirming the method of correlating total carbon deposits with the carbonization index has been obtained on an assortment of engines. This information is presented graphically in Fig. 9 when using oils *A* and *B*.

Effect of Varying Engine Conditions

While the foregoing work shows clearly that a relation between rate of carbon deposition and total volatility of the oil does exist, it does not give a correct impression of the value and limitations of this relation in actual engine-performance. For example, if the temperature of the combustion-chamber surfaces changes materially with a change in operating conditions, two given oils having different carbonization indices can be expected to show different relative tendencies to deposit carbon. Figs. 10 and 11 show the effect of varying load upon the carbon-depositing tendencies of two oils differing by approximately 200 deg. fahr. in carbonization index. With the exception of the varying load-factor, these tests were run under the conditions outlined in Table 1.

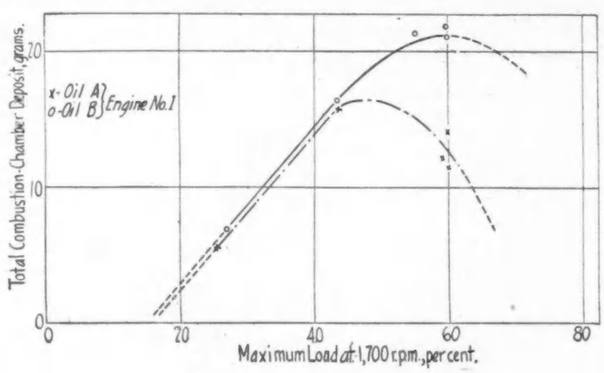

FIG. 10—THE EFFECT OF ENGINE LOAD ON COMBUSTION-CHAMBER DEPOSIT

Over a Test Period of 50 Hr. at Rather Light or Heavy Loads, No Great Differences in Oils of Radically Different Volatilities Are Apparent. For Engine No. 1, the Jacket-Water-Outlet Temperature Was 175 Deg. Fahr., and That of the Oil 170 Deg. Fahr., the Engine Speed Being 1700 R.P.M.

It will be noted that at the light loads the combustion-chamber-surface temperatures were evidently so low that the rate of carbon formation was very low with both oils. As the temperatures rose with increasing load, however, carbon formation became more rapid and the difference between the oils very marked. At the higher loads, the temperatures evidently have reached the point where evaporation and, possibly, oxidation again prevent either oil from forming any great amount of carbon. As will be noted, the jacket temperatures have been held constant throughout these tests and the mixture ratio at the light loads because of the high water-temperature was comparable to that at higher loads and, therefore, the opportunities for the accumulation of the sooty type of deposit due to rich mixtures at light loads have been minimized.

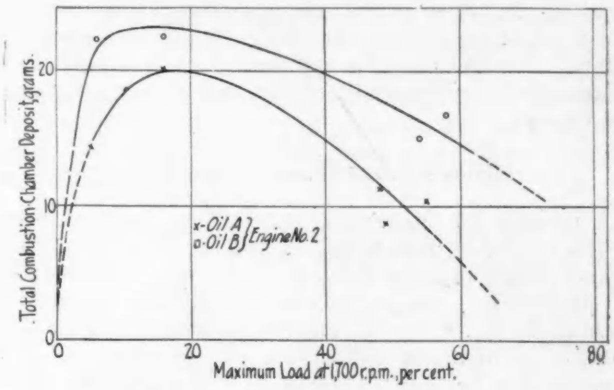

FIG. 11—THE EFFECT OF ENGINE LOAD ON COMBUSTION-CHAMBER DEPOSIT

On This Engine the Differences between Oils of Different Volatilities for Most Load Conditions Were Noticeable. For Engine No. 2 the Jacket-Water-Outlet Temperature Was 175 Deg. Fahr. and That of the Oil 170 Deg. Fahr., the Engine Speed Being 1700 R.P.M.

The tendency of carbon deposits to accumulate with time is probably of greatest interest. Fig. 12 shows the behavior of the two oils used in the previous tests when used for periods of varying length under the conditions described under Engine No. 1 in Table 1. It will be noted that the deposit from each oil tends to reach an equilibrium value. Brooks[6] has indicated the phenomenon somewhat, but his tests unfortunately extended to only 48 hr. and equilibrium was not reached in his work. Equilibrium probably represents the thickness of deposit required to provide sufficient heat insulation to raise the surface temperature to the point at which the oil will be evaporated rather than remain to be subjected later to slow cracking and oxidation. In the case of the oil having the higher carbonization index, a much thicker insulating layer of carbon is required than in the case of the more freely evaporating oil.

Fig. 12 again suggests the possibility that total deposit, dirt and oil included, should be considered rather than carbon content alone, as it might be expected that inorganic matter will play its part in providing thermal insulation and should therefore count as a part of the

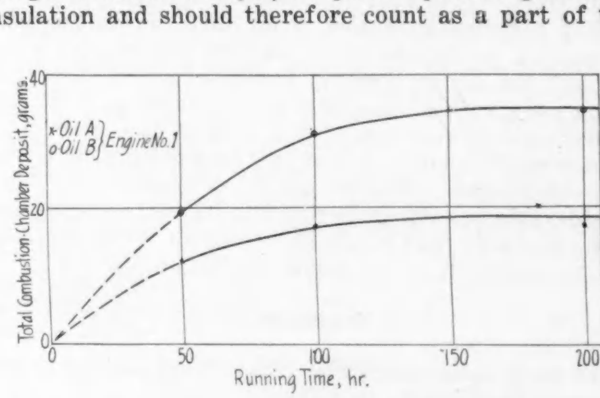

FIG. 12—THE EFFECT OF DURATION OF TEST ON THE COMBUSTION-CHAMBER DEPOSIT

Under the Engine Conditions Indicated the Oils Tested Showed an Equilibrium in Regard to Combustion-Chamber Deposit after Approximately 100 Hr. of Running Had Been Completed. For Engine No 1 the Jacket-Water-Outlet Temperature Was 175 Deg. Fahr., and That of the Oil 170 Deg. Fahr. The Engine Load Was 55 to 65 Per Cent of Maximum Power at 1700 R.P.M.

[6] See THE JOURNAL, January, 1926, p. 48.

deposit. In other words, we may expect that, under a given set of conditions, the thickness of the deposit obtained from the use of a particular oil may tend to be substantially independent of the actual composition of the deposit.

Miscellaneous Observations Made

A number of interesting points have been observed in the course of this work. Figs. 10, 11 and 12 show clearly that comparisons made under one particular set of arbitrarily chosen engine conditions cannot be counted upon to give a reliable picture of the general relative carbonizing tendencies of the oils. In particular, this is true of tests of comparatively short duration. For example, the bulk of the comparative tests presented herewith were 50 hr. in length at load factors between 55 and 65 per cent. In all probability, 25-hr. tests would have been almost worthless because even two such radically different oils as are illustrated in Fig. 12 were both so far from equilibrium as to carbon deposition that no very great difference between them was apparent. Further, the total deposit for such a short time is usually so small that the precision with which it can be removed and collected is not particularly good. Accuracy may still be further impaired by the circumstantial presence of rust and other accumulations from around the gasket. In general, the data indicate 50-hr. tests to be entirely satisfactory, although under those conditions in which the deposits are relatively small, somewhat better accuracy might be expected from 100-hr. runs.

The observations of Gruse that the amount and the hardness of carbon deposits in general go hand in hand have been verified in the foregoing work. In fact, the deposits given by some of the oils having the highest carbonization indices were so hard that they could be removed only with great difficulty. In some cases where aluminum-alloy pistons were employed, the carbon could not be removed without partly removing some of the metal. The labor involved in removing deposits of this character is much greater than that required for the softer carbon formed from oils lower in carbonization index.

In view of the current tendency toward the use of higher compression-ratios than have heretofore been attempted, predicated upon keeping the engine clean through the use of chemical carbon-removers, the foregoing work raises some interesting questions. In particular, whether an engine can be kept free from hard dense deposits with facility by the use of a "solvent" is problematical. But the use of oil coolers may be of considerable assistance in minimizing carbonization, as they eventually may result in the use of lower viscosity and, consequently, more easily volatilized oils.

Summary

The work upon which this report has been based can be summarized briefly as follows:

(1) Carbon deposition, insofar as characteristics of the oil are concerned, can be predicted from its carbonization index; that is, the temperature at which 90 per cent has been evaporated in a simple distillation at an absolute pressure represented by 1 mm. of mercury.

(2) The Conradson carbon-residue test is not a reliable criterion for the carbon-forming tendency of an oil.

(3) Carbon deposition seems to be substantially independent of oil consumption, at least within fairly wide limits.

(4) Carbon does not accumulate indefinitely, but tends to approach an equilibrium dependent upon the thickness of deposit required to raise the surface temperature to the point at which rapid and complete exaporation occurs.

(5) At light and at heavy loads, carbon deposition is not profoundly affected by oil characteristics. In the engines investigated it apparently reaches a maximum at a load factor under 60 per cent at 1700 r.p.m.

(6) Short test-runs appear to be generally unreliable. At least 50-hr. tests are desirable in comparing the carbon-forming tendencies of oils.

Distillation Apparatus Details

When the work reported herein was begun the fact was realized that the exact criterion to be used to indicate the effect of volatility on engine carbon-formation would depend on the mechanism of this formation, and this was not precisely understood. It seemed reason-

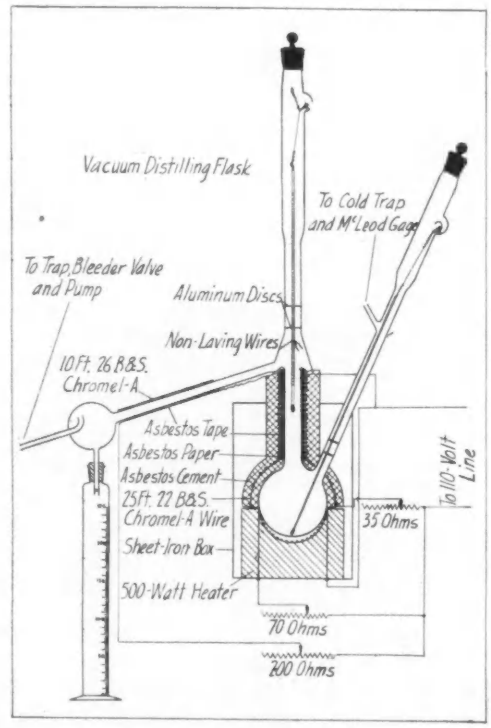

FIG. 13—APPARATUS USED TO DETERMINE THE DISTILLATION OF THE OILS UNDER A PRESSURE OF 1 MM. OF MERCURY

able, however, that the effect could be measured by total volatility, which, in turn, can be measured by the temperature at which the oil is just completely vaporized in contact with the total vapors produced, which is also the temperature at which the first drop will condense from an infinite quantity of vapor of the composition of the oil in question.

In the case of lighter distillates, this temperature can be determined directly by any of several different methods for determining the equilibrium boiling-point[7]; but, in the case of high-boiling-point oils, these methods

[7] See THE JOURNAL, November, 1921, p. 313; see also *Journal of Industrial and Engineering Chemistry*, October, 1921, vol. 13, p. 906; and *American Petroleum Institute Bulletin* No. 27, p. 116.

fail. Even if they could be adapted to such cases, they are laborious and time consuming. However, investigations in this laboratory have shown that a relation exists between this total-vaporization temperature and the ordinary batch distillation, such as the A.S.T.M. distillation, and that the 90-per-cent point on a batch distillation should be closely related to the total-vaporization temperature for high-boiling-point oils. We decided, therefore, to develop a standard and reproducible batch-distillation process which would be applicable to high boiling-point oils, and, using the 90-per-cent point at a pressure represented by 1 mm. of mercury as a carbonization index, to compare engine-carbon formation with this index.

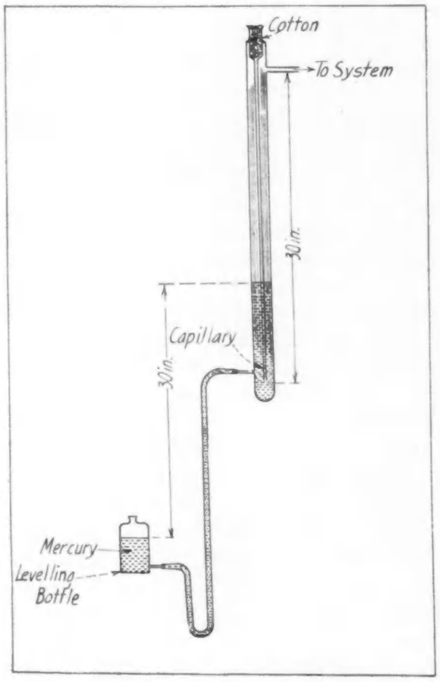

FIG. 14—A PRESSURE-REGULATING VALVE OF THE CAPILLARY RESISTANCE TYPE

The apparatus for the determination of the carbonization index is shown in Fig. 13. The parts not shown in the figure are a Megavac pump to produce the vacuum, a needle valve to admit air to hold the pressure constant, and a McLeod gage. The pump and gage are protected with traps cooled with acetone and solid CO_2. In using the apparatus, 200 cc. of oil is charged into the flask through the long side-arm. A few small carborundum crystals are added to prevent bumping, the thermometer is returned to position and the stopper is placed in the side-arm. The apparatus is evacuated to about 15 mm. of mercury and the supply of heat to the neck is turned on. When the neck temperature reaches 250 deg. fahr., the pressure is reduced to that of 1 mm. of mercury and the heat supply to the flask proper is turned on. This method of procedure is necessary to prevent foaming of the oil over into the condenser due to traces of dissolved water and air. The temperature of the oil is raised gradually to the boiling-point, meanwhile keeping the system regulated to a pressure of 1 mm. of mercury by the adjustable resistance-leak ahead of the pump. During the distillation the heating current in the neck is regulated so that the vapor temperature is a few degrees above the liquid temperature. At each 5 per cent distilled, the pressure is measured and the leak altered if necessary. After the first 10 per cent, the pressure is easily kept constant to well within 0.05 mm. of mercury. Distillation is discontinued after 90 per cent has been distilled.

Regulation of the two heating coils may appear difficult at first; but, after some practice, the two temperatures can be easily kept within 2 or 3 deg. of each other. The distillation can be carried out in 1 hr., regulating pressures and temperatures to very close limits. It is essential that the non-laving wires have good contact with the thermometer and to prevent wetting the bulb with relatively cold liquid running down from above. When this works correctly, no reflux will be returned to the flask and the distillation can be checked within very close limits; 1 to 2 deg.

Most of the condensation occurs in the alembic in the neck of the flask, and warming the draining arm to reduce drainage lag to the minimum is necessary. In the apparatus shown, drainage lag amounts to about 2½ per cent; hence, the observed 87½-per-cent point is the true 90-per-cent point. Stem corrections were made on the thermometer readings where necessary.

The manually operated needle valve for regulation of pressure can be replaced by a capillary resistance valve. One such valve which was found to give very satisfactory results is shown in Fig. 14. It was constructed as follows: A 6-mm. Pyrex-glass tube was drawn to a fine capillary about 90 cm. long and sealed as shown into a 13-mm.-diameter Pyrex-glass tube having connections such that it can be connected to the system and a mercury leveling-bulb. Previous to sealing-in the capillary leak, 10 other sealed capillaries were loosely placed in the outer tube. These, in operation, serve to furnish paths to the surface for the bubbles of air, thus minimizing fluctuations in mercury height. The capillary leak was protected against dust by a cotton plug. This automatic leak was placed in the system in parallel with a needle valve, the latter being used for releasing pressure after the completion of the distillation and for regulating the pressure to approximately 10 mm. of mercury during the period of degassing and warming the neck of the flask.

During the distillation the pressure was regulated by the automatic leak. This required one setting of the mercury leveling-bulb at the beginning of the distillation. With the capillary chosen for this work the resistance valve was quite sensitive, a change of 1 mm. of the mercury level producing 0.001 mm. difference in pressure at 1 mm. of mercury within the system. For guidance in the construction of such a valve it should be pointed out that a capillary which will maintain about 1.3 mm. of mercury without the use of mercury should be satisfactory.

Conclusions

The research described indicates that the combustion-chamber carbon-forming properties of an oil are indicated with a satisfactory degree of reliability by its total volatility. A carbonizing index for motor oils can be obtained by determining the temperature at which 90 per cent has been evaporated in a simple distillation at an absolute pressure corresponding to 1 mm. of mercury. The Conradson carbon-residue value seems not to be a generally reliable carbonization criterion.

It was also noted that carbon deposition appears to be substantially independent of normal variations in oil consumption, and also that it tends to approach an equilibrium which represents a deposit of sufficient heat-insulating ability to keep the surface temperature at a level which assures complete volatilization of the oil. It is evident also that engine-test runs must be of appreciable duration to obtain reliable results; 50 hr. seems to be satisfactory, but 100 hr. may be desirable when deposits are small. The influence of total oil-volatility on carbonization has been verified in a number of engines representing the principal types in general use.

Transoceanic Airship Service

(*Concluded from p.* 199)

The airships for transatlantic service are designed to carry 25,000 lb. of mail and express in addition to 80 passengers and an adequate margin of fuel and ballast.

First class mail movement across the Atlantic amounts to approximately 35 tons per week each way. With four airships giving sailings twice a week, the total mail-capacity of the line would be 25 tons weekly. Thus, the airship service offers an opportunity to speed up a majority of all the first-class mail available. This is not a question of a small volume of premium air mail, but a service to the letter mail of two continents cutting to less than one-half the apparent width of the separating ocean. Our hope is to carry the ordinary first-class mail and give Americans a reply from their European correspondents in just a week.

The passenger traffic that may be developed for a transatlantic airship line will depend upon the demonstration over a period of time of the reliability, safety and comfort of this new mode of travel. The extent of the patronage during the initial years of operation is entirely speculative, but we are confident that if rates are less than twice steamer fares the public will support the service. In 1929 the total eastbound passenger movement over the Atlantic from all North American ports are 511,000, of whom 100,000 went first class. In that year nine leading liners carried about one-half of all first-class passengers, or 50,000 persons each way, who paid extra fare to go faster. If we consider that the potential traffic for the airship line is represented by the number of passengers paying $500 or more on the faster liners, we find about one-half of the passenger list, or 25,000 people, in this price class. Four airships could take about one-quarter of this number, or less than 8 per cent of all first-class passengers.

Will Create New Patronage and Business

In any new transportation facility, it is fallacious to assume that the patrons will come from patrons of the existing service. The new facility creates and attracts new patronage in proportion to its value. Cutting down the travel time to Europe by one-half should stimulate travel by at least 4 per cent and hence create new business enough to support it without taking any business away from the steamships; indeed, R. Stanley Dollar has said that if airships can carry our business representatives abroad in half the time, they will go oftener, get more business and inevitably create more passengers and freight for the regular steamship lines.

A steamship, to maintain a reliable five-day service, costs nearly twice as much as a six-day ship, while the cost of a four-day ship is prohibitive. It can be shown that, for the cost of one super-steamship, a complete semi-weekly airship service with four airships and a terminal on each continent could be established. Such an airship line could serve all the traveling public that has any legitimate reason to demand superior speed and could save two or three days' time en route instead of the maximum of one day saved by a subsidized super-steamship.

Allowing for future improvements in airplanes which may make longer flights with payload, and allowing for other improvements to make such flights safe enough for commercial purposes, we find that the airship still remains substantially more economical than the airplane for large loads. After an extensive study of the situation, we believe that the airship and the airplane are not competitive; the airship is best suited for large loads, especially of passengers, on long non-stop flights and a sailing frequency comparable with that of steamships; the airplane can give a frequent schedule comparable with that of the railroad, with small loads and frequent stops to refuel. The airship, under such conditions, costs something less than $1 per ton-mile of payload and the airplane perhaps $2 per ton-mile. When the airplane non-stop distance exceeds 1000 miles, the ton-mile costs also become prohibitive. The airship ton-mile costs also become prohibitive if its large payload capacity is not utilized.

The Field for Synthetic Lubricating Oils

Discussion of Semi-Annual Meeting Paper Prepared by F. W. Sullivan, Jr., Vanderveer Voorhees, P. T. Oak and D. P. Barnard[1]

DISCUSSERS unanimously congratulate the authors and regard their research work of importance as marking the start of developments of great value. The process involved and the limited quantity of wax used as basic material will make the synthesized oils always two to three times as costly to produce as the usual motor oils, but their use for certain purposes will be compensated by lower cost of manufacture of mechanical parts. Oils that change less in viscosity with temperature changes than do present oils are greatly needed for easier engine-starting and for shock-absorbers and transmissions. A line of oils said to have rather similar characteristics to those of synthetic oils has been produced by the use of aluminum chloride and marketed commercially for about three years in the usual price ranges of the better-quality lubricants for aviation, motor-vehicle and marine engines. Various points regarding the synthetic process and the properties of the new oils are also discussed.

Tests of synthetic oils by the Materiel Division of the Air Corps are described in written discussion and the results indicate a superiority of these oils as regards low-temperature characteristics, carbon deposition and engine wear, and that the oils are satisfactory in oiliness and lubricating properties.

CHAIRMAN GEORGE L. MCCAIN[2]:—In this era of increasing speed and the more general use of automotive equipment, nothing can be more important from the operator's viewpoint than lubrication. The lubricating-oil engineers have been working in close harmony with the automotive engineers for years, and as a society we owe them a debt of gratitude for their cooperation. Synthetic oils present a new angle and give us a lubricant that is ideally adapted for certain uses.

A. E. BECKER[3]:—The ideal condition for the lubrication of any machine is that the lubricant used shall have the same viscosity under all operating conditions. Two methods by which this ideal may be approached are

(1) All working parts of the machine may be kept at the same temperature. It is then merely a question of selecting an oil of suitable viscosity and stability at the operating temperature, a condition that is well approached in the case of a watch.

(2) In machines such as the automobile, the various operating parts of which are not only at widely different temperatures but the machine as a whole is expected to function equally well in winter and summer, a lubricant the viscosity of which remains constant with change in temperature would be ideal.

The authors of the paper are to be congratulated upon having taken a step in this latter direction. Such high viscosity-index oils as they describe should prove useful for a variety of purposes, as pointed out; but stable motor oils of high viscosity-indexes, low pour-points and low Conradson carbon, whether produced by this or other methods, are of equal or even greater importance.

Requirements for Easy Cold-Starting

In a paper[4] presented before the New England Section of this Society last February I drew the following conclusions, among others:

> The relation of friction horsepower to starter horsepower and engine power at low speeds is the real controlling factor. It is important for the manufacturer to so design his engine and starting equipment that, as soon as firing occurs, the power developed will be sufficient not only to kick out the starter but to maintain operation and rapidly accelerate the engine.
>
> The viscosity of the crankcase oil at the starting temperature is of great importance. Regardless of what the manufacturer should do, this viscosity must be low enough to permit the engine as designed to carry the friction load as soon as it fires. Otherwise the engine will stop.
>
> It is not necessarily true that low-pour-point oils will establish lubrication more rapidly than high-pour-point oils. The viscosity of the oil at the crankcase temperature is as important as the pour-point.
>
> The less the viscosity of the motor oil changes with temperature, the easier will be the problems of the engine manufacturer and of the customer.

The present paper is new evidence that the petroleum industry is striving to give the public better and more satisfactory products. The automotive industry is trying to do its part by adopting methods for maintaining more uniform temperatures throughout the engines. Such problems should be approached from both angles. In carrying out this work we hope that there will be enough cooperation between the two industries to avoid situations similar to that now existing in the fuel field, in which vapor-lock difficulties prevent the full utilization of the benefits to be derived from the use of fuels of high volatility. As an example in the present case, the car manufacturer should continue his efforts to improve the design of transmissions and differentials

[1] The paper was published in the S.A.E. JOURNAL for July, p. 40. Mr. Sullivan and Mr. Voorhees are research chemists with the Standard Oil Co. (Indiana); Mr. Oak and Mr. Barnard are research engineers with the same company. Mr. Oak is a Junior Member and Mr. Barnard, who presented the paper at the meeting, is a Member of the Society. Several errata to the paper as published are printed following the discussion given herewith.

[2] M.S.A.E.—Research engineer, Chrysler Corp., Detroit.

[3] M.S.A.E.—Standard Oil Development Co., New York City.

[4] See *Automotive Industries*, March 7, 1931, p. 401.

so that the use of lubricants to lessen noise and leakage will be less necessary and thereby make possible the realization of the full advantages of high viscosity-index oils for transmission and differential lubrication.

Will the authors explain how the viscosities of their oils change with application of pressure? It is hoped that they will continue their efforts to classify the viscosity-temperature characteristics of oils on a temperature basis.

NEIL MACCOULL[5]:—The authors should be congratulated for expressing viscosities in absolute units. To designate viscosities on the Saybolt scale vastly above where the Saybolt instrument can ever take such readings seems to me to be absurd. For people to adapt their minds to a scale of absolute units is not very difficult. Charts expressing a scale of Saybolt equivalents for absolute units are available, and I hope that more of these very high viscosities at low temperatures will be expressed in absolute units instead of Saybolt viscosities in the neighborhood of 10,000,000 Saybolt sec.

Engine-Oil Improvement Most Desired

A. L. BEALL[6]:—The authors seem to me to have gone a long way, even in their experimental stage, toward satisfying some of the design engineers' demands for improved lubricants. Whether price will have any effect on the use of such lubricants will be interesting to observe.

Low pour-point oils, which make starting reasonably easy, seem to be more important now for aviation engines than a few years ago. At several western mountain airports last winter I saw a number of engines started that had been standing out over night. Invariably the oil was left in the crankcase, and from two to five men, one after another, would exhaust their strength on the starter to get the engine going, and when the engine did start it was rather well flooded with raw fuel. Improvement in engine oils seems to me to be the most important consideration.

Synthetic Method Should Yield Valuable Information

SAMUEL P. MARLEY[7]:—This paper undoubtedly entitles the authors to hearty congratulation by anyone interested in the constitution of lubricating oils or their application. That they have deemed it desirable to spend so much time on pure hydrocarbons and their reactions is particularly encouraging. This method, which has been too much neglected in the past because petroleum materials were regarded as too complicated in their make-up for this manner of approach, is evidently capable of yielding valuable information in many fields.

A highly important question concerns the "oiliness" of these synthetic oils as compared with that of natural petroleum lubricants. Oiliness has, in general, been attributed to the presence in a liquid lubricant of constituents that are readily absorbed by the metal surfaces to form films made up partly of metal molecules and partly of lubricant molecules on which the actual load is carried. The suggestion has frequently been made that the absorbable components of a natural petroleum lubricating oil fall in the class of what are broadly called "unsaturated compounds," and that a too drastic refining is undesirable in that it would remove the really valuable lubricating constituents. The familiar statement that white oils are unsatisfactory lubricants is a case in point. The present synthetic lubricating oils, particularly those made from the pure olefin hydrocarbons, should presumably be quite free of the mysterious borderland unsaturated substances which are generally believed to be so valuable, and it would seem that a good test case could be made here. At least the constituents of such a polymerized mixture could be learned with a greater degree of accuracy than would be possible for a natural petroleum product and some light might be cast upon this very difficult question.

Some information on whether the synthetic products include only olefinic substances or also naphthenes would be of value. The ability of aluminum chloride to convert olefinic substances into naphthenes has often been mentioned in the literature of the subject.

In their discussion of the use of the synthetic oils for crankcase lubrication of engines at elevated temperatures, the authors have expressed oil consumption in pounds per brake horsepower per hour. This seems slightly questionable, as the variation of power output includes two factors that would seem to be independently variable, at least hypothetically. These are engine temperature and the level of the pressure cycle in the combustion-chamber. As temperature increases, oil consumption generally rises, but, as the throttle is opened for higher loads, the pressure cycle inside the combustion-chamber as a whole is moved to higher pressures. That is, not only is the pressure during the compression stroke higher but also, because of the more widely opened throttle, the pressure during the suction stroke is appreciably higher. These higher pressures in the combustion-chamber tend to produce lower oil consumption, while the elevated temperatures tend to increase it.

High-Quality Oils Made by Polymerization

CHARLES R. NOLL[8]:—The work of Mr. Barnard and his associates shows that oils of exceptionally high quality can be made by this new process, which makes particular use of aluminum chloride.

The company with which I am connected has for the last few years marketed a line of superior lubricants in the manufacture of which aluminum chloride is used, although the refining process is of a different nature from that described in the paper. However, the desirable characteristics of the resultant oils are very similar. Specifications of two of these grades, which possess similar characteristics, such as desirable viscosity index, high flash and fire-points, low Conradson carbon percentages, high resistance to oxidation and low pour-points, are as follows:

	Gulfpride Oil 75	Gulfpride Oil 200
Gravity, A.P.I. deg.	29	27½
Flash, open cup, deg. fahr	450	610
Fire, open cup, deg. fahr.	510	670
Pour-Point, deg. fahr.	0	10
Viscosity, Saybolt universal sec. at 100 deg. fahr.	720	3,500
Viscosity, Saybolt universal sec. at 210 deg. fahr.	75	200
Color, N.P.A.	3	4½
Carbon (Conradson), per cent	0.19	0.40

The pour test of these oils could, by suitable rearrangement of the refining schedule, be reduced consid-

[5] M.S.A.E.—Automotive engineer, research duties, The Texas Co., New York City.
[6] M.S.A.E.—Engineer, refined-oil department, Vacuum Oil Co., New York City.
[7] M.S.A.E.—Research engineer in petroleum technology, Mellon Institute of Industrial Research, Pittsburgh.
[8] M.S.A.E.—Automotive lubrication engineer, Gulf Refining Co., Pittsburgh.

erably at a somewhat increased cost, if it were found necessary or desirable to do so. They have been marketed commercially for approximately three years in the usual price ranges of the better-quality oils.

Oils of this series are manufactured in five viscosities and are recommended especially for lubrication of aviation engines and for use in motor-cars and marine engines where the operator is interested in using oil of this high quality. We have also had considerable success with them for lubrication of transmissions and differentials.

J. P. STEWART[9]:—With reference to the viscosity curve shown in Fig. 1, we have rather good evidence that the upward trend of the curve caused by the pour-point is not reflected in additional resistance in engine starting. The departure from the straight line is caused by the wax structure which influences the results with the relatively light stresses produced in the viscosity measurement even where pressure is employed. Apparently, under conditions of engine starting, that stress becomes sufficient to completely overcome the plastic resistance, and the resistance follows the projected viscosity line, as indicated, rather than the curve line. In taking the viscosity, you could undoubtedly get it down if a sufficiently high pressure were used. Such pressures, however, do not seem to be feasible for routine measurements.

High Cost Should Not Deter Further Work

A. L. CLAYDEN[10]:—The situation with regard to special products of the nature described in this paper reminds me of the situation the automobile industry faced about 25 years ago with regard to steels. At the beginning of the Society and its standardization work, the steel producers of the United States were not in the least interested in anything but ordinary steel. With hardly any exception, if a particularly high-tensile steel was wanted, one had to get it from Europe. The steel industry of this Country, with possibly unimportant exceptions, could not see that any money was to be made out of a small market for a product that was very difficult to make. That situation changed rapidly, and probably the best alloy steels in the world today are being made in this Country, but they still have a very limited application. The fact that we can get steels today four, five or six times as strong as the steels we could obtain with equal ease 25 years ago does not mean that we have given up using cast iron for crankcases. So, whatever may be done in the way of making special products of any kind from petroleum as the raw material, they are not likely to displace to any great extent the simpler product which, so far as one can foresee, must always be cheaper and more easily obtained.

A tendency always exists to try to force any new material that appears into engineering applications where its use is not really justified. In the case of the synthetic oils, the work described probably represents only a start, so far as the viscosity-temperature characteristic is concerned, and indicates that a great deal more can be done. That is of great importance for certain specific purposes, and the cost of the material is of almost no importance, as in shock-absorber application, because of the comparatively small quantity of oil required and its use for a very long time. On the other hand, if large quantities of oil are needed to lubricate some kind of mechanism, then the cost becomes of great importance.

The history of the petroleum industry for the last 10 years has shown that almost anything can be done with petroleum if the incentive is strong enough. While the material described represents a great accomplishment, the authors of the paper doubtless will agree that it is probably just a start toward what can be done if we can work along this line with the idea of producing a lubricant to fill a special need that warrants a special price, and that it is not suggested that all of our oils in the future will be controllable in any way we desire, because every time that work is added to a raw material the cost is increased.

More Stable Viscosity with Temperature Changes Needed

WILLIAM G. WALL[11]:—This work is unquestionably in the right direction; it is very much needed, but the importance of the results depends greatly upon the purposes for which the material is to be used.

Some time ago, after a car had been run over rough roads at considerable speed, the hydraulic shock-absorbers were removed and were found to be at rather a high temperature, about 140 deg. fahr. I was surprised to note that the resistance of the shock-absorbers had been reduced to a very small amount. We reduced the temperature about 75 deg. and the resistance went up nearly 100 per cent. I do not mean to imply that all shock-absorbers would show that difference, nor that all lubricants used in them would show any such a difference in viscosity, but this case shows that we must have a lubricant or a liquid the viscosity of which stays somewhere near constant, to get the best results from hydraulic shock-absorbers.

Another make of hydraulic shock-absorber subject to the same test a little later showed a difference of only about 30 per cent in resistance with a change of 75 deg. in temperature; but even this is entirely too much.

Extra Cost Warranted for Special Uses

T. C. SMITH[12]:—I have been interested in this paper because the work described is leading toward an oil having a viscosity index and a pour-point that will certainly be of a great deal of assistance in connection with steering-gear lubrication, shock-absorber work and the two gearsets in the car. The available lubricants are usable, but we are having troubles that I am sure further development along this line will greatly minimize.

Will Mr. Barnard tell us if there is any indication as to whether we shall be able to buy these oils at somewhere near a reasonable price?

D. P. BARNARD:—As far as we can foresee, no reason exists for hoping that these oils will become as generally available as the conventional type of motor oil is at present. As indicated in the paper, our starting point is paraffin wax. We must have a saturated straight-chain basis upon which to work. The amount of wax that is available in the entire oil industry at present is exceptionally small as compared with the total amount of lubricating oils required. Furthermore, as Mr. Clayden pointed out, as we increase the amount of work done on the oil, the price must go up.

[9] M.S.A.E.—Head, automotive laboratory, research department, Vacuum Oil Co., Paulsboro, N. J.

[10] M.S.A.E.—Research engineer, Sun Oil Co., Philadelphia.

[11] M.S.A.E.—Consulting engineer, Indianapolis.

[12] M.S.A.E.—Engineer, motor-vehicles and labor-saving machinery, American Telephone & Telegraph Co., New York City.

I should say, off-hand, that, unless these oils are worth two or three times as much as the conventional type of motor oil, they will probably not be actively produced. Their principal advantage is that the use of a relatively small quantity may make possible some saving in a manufacturing process. The case of the shock-absorber ideally illustrates that.

Synthetic oils may logically be employed where the use of a high-viscosity fluid permits a wider manufacturing tolerance and the extra cost of such a product can be more than offset by the saving in shop cost through reduction of the number of rejects, or where a product which can stand engine operation at extremely high temperatures will permit of enough advantage in some other point of performance to more than pay for the cost. For example, if letting an engine run at very high temperature will save enough head resistance on an aviation engine, possibly the extra cost might be justified. We have at present almost no method of computing the probable cost of these products. They can be made within reasonable limits provided some real tangible benefits can be derived from their use.

In reply to Dr. Becker's question about the effect of pressure upon the viscosity of these products, we have no data at present as to the effect of static pressure upon viscosity.

Mr. Stewart raised the point that in Fig. 1 the upper curvature of the paraffin type of oil at a temperature below the pour-point had no particular bearing upon engine-cranking resistance. That agrees exactly with our experience. However, in some other uses, notably in the transmission, we do get what might be called cold-test effects to a much greater extent, and at temperatures well below the cold test the presence of wax has considerable effect upon shifting effort.

Air Corps Tests of Synthetic Oils

S. D. HERON[13]:—The synthetic oils described in the paper appear to be of distinct interest for aircraft use, especially for very cold weather operation. Where aircraft engines have to be started without heating in atmospheric temperatures well below 0 deg. fahr., the combination of very flat temperature-viscosity curves with exceedingly low pour-points of these oils indicates that they are superior to any natural oils for such use.

For equal viscosity at 210 deg. fahr., these oils seem to be of lower viscosity at temperatures below 0 deg. fahr. than any natural oils which are then below their pour-points. Thus the synthetic oils should give lower starting friction and better pumpability than the natural oils.

In view of the very favorable low-temperature characteristics of these oils, the Materiel Division of the Air Corps conducted tests to determine if the advantages were obtained at the expense of undesirable characteristics as regards engine lubrication. It had been suggested that the oils produced a very hard and undesirable form of carbon and that they lacked oiliness.

Very highly accelerated tests for determination of piston-ring sticking, piston carbon formation and oil-breakdown characteristics were therefore conducted on a single-cylinder engine at 350 deg. fahr. cooling-liquid temperature. The test procedure used has since been found to be misleading as regards the relative behavior of oils in multicylinder engines. The lack of correlation between the multicylinder and single-cylinder-engine results probably is due to the fact that in the latter case the test was so highly accelerated as to produce a viscosity increase in the test period about five times as great as occurs in multicylinder engines of the air-cooled type even when oil is not changed and fresh make-up oil merely added.

The results of the single-cylinder tests of the oils described by the authors showed that the formation of carbon behind the piston-rings and in the interior of the piston was exceptionally low and that the type of the carbon was not more objectionable than that obtained from natural oils.

As a result of the single-cylinder tests, tests were carried out on two multicylinder air-cooled engines. The first test was on a supercharged Pratt & Whitney SR-1340 engine, which had not had previous service and which was run for 50 hr. under standard endurance-test conditions (90 per cent of the time at 90 per cent of rated power and 10 per cent of the time at rated power) at a rated power of 500 hp. at 2200 r.p.m. with oil of 77-sec. Saybolt Universal viscosity at 210 deg. fahr. and 730 sec. at 100 deg. fahr., with a pour-point of —35 deg. fahr. This was specifically carried out to determine if the oil could be used in winter without excessive consumption or engine wear.

As the oil was of low viscosity for such an engine, the "oil in" temperature to the engine was held at 105 deg. fahr., which is the approximate operating value normally encountered with such engines in winter use. The oil consumption after the first few hours fell to 10 lb. per hr., which is similar to that obtained with oil of 120-sec. Saybolt viscosity at 210 deg. fahr. and an "oil in" temperature of 160 deg. fahr.

Comparative Tests Give Satisfactory Results

At the conclusion of the test, no evidence of lack of oiliness or lubrication could be found in any part of the engine. As regards the piston-rings, the indications were the converse of lack of oiliness, as all pistons had some rings which were not completely seated. This condition does not occur when lubrication is inadequate, but rather does rapid ring-seating and wear result. The condition of the bearing surfaces of the pistons was exceptionally good and the amount of deposit in the ring grooves, on the outside of the skirts and on the inside of the pistons was exceptionally low.

A comparative test of the oils described in the paper against Mid-Continent oil, Pennsylvania oil and another synthesized oil was carried out on a Wright R-1750-B engine. The range of Saybolt viscosities of the oils used was from 113 to 122 sec. at 210 deg. fahr. This engine was chosen for the test as the large rib surface inside the pistons which is in contact with the oil results in weighable quantities of carbon being formed in the piston interiors in relatively short periods with normal oils. Each of the oils described above was tested for 25 hr. with the engine running at 90 per cent of full power. At the conclusion of each test period, the pistons were removed and the weight of deposit determined to the nearest 10 mg. on (*a*) the tops of the crowns, (*b*) the ring grooves and the outside of the skirt, and (*c*) the "waffle iron" ribs and all other portions of the interior.

All oils gave very satisfactory lubrication under the test conditions used and, as was expected, no sign of ring-sticking was detected. The amount of deposit on the tops of the crowns, which is considered the least important of the deposits, was lowest for the Mid-Continent oil and approximately equal for the Pennsyl-

[13] S.M.S.A.E.—Mechanical engineer, Materiel Division, United States Army Air Corps, Wright Field, Dayton, Ohio.

vania oil and both synthetic oils. Both synthetic oils were better than either of the normally refined oils as regards ring-groove and piston-skirt deposits. In this respect the Pennsylvania oil was least favorable. As regards deposits inside the pistons, one of the synthetic oils was much the best, the Pennsylvania next best, followed by the other synthetic oil, the Mid-Continent oil being much the worst in this respect. It is considered that the ring-groove deposits are much the most important, as ring-sticking will produce piston failure, which neither deposits on the top of the crown nor in the interior are known to do. Thus, in the most important phase of deposits from the lubricating oil, the synthetic oils appear to advantage in relation to the oils produced by normal refining methods.

A third test on a multicylinder air-cooled engine of one of the above synthetic oils (not one of those described in the paper) against a Pennsylvania oil meeting the requirements of United States Army Specification 3556-8, Grade 120, but of different make from that used in the above test, showed the synthetic oil to be markedly superior as regards ring-groove deposit.

The work of the Air Corps on the comparative engine-testing of lubricating oils has indicated that the subject is exceedingly complex, that reproducible results are obtained only with great care, and that a single-cylinder test technique must be determined which produces results in accord with relative multicylinder-engine ratings of widely different oils.

As trouble with oil breakdown and formation of decomposition products is confined almost entirely to modern engines with relatively high cylinder-temperatures, it is believed that such tests are of most value when made at relatively high cylinder-temperature.

A more complete comparison of the low-temperature viscosity characteristics of the synthetic oils described in the paper with natural oils would be possible if the pour-points of the natural oils in Fig. 1 were given.

No information is given in the paper as to the probable range of molecular weights and probable molecular structure in the finished commercial oils described. If approximate data on these points are available they would be of interest.

CORRECTIONS IN SYNTHETIC-OIL PAPER

Since publication of the paper on The Field for Synthetic Lubricating Oils, in the S. A. E. JOURNAL for July, beginning on p. 40, D. P. Barnard, 4th, one of the authors, has forwarded the following corrections:

Fig. 1.—At the left of the first vertical scale, the word "strokes" should read "Stokes," after Sir George G. Stokes, a pioneer in viscosity calculations.

Table 2.—The last figure in the first column should read 1.85 for Sligh oxidation, instead of 1.8.

Table 3.—The heading over the last column should read, Maximum Viscosity Permitting 2-Sec. Shift with 3-Lb. Effort.

Table 8.—The heading over the two middle columns of figures should read, Sludge, Mg. per 10 Grams.

In the text on page 43, under the cross-head, Shock Absorber Fluids, "1300 poises" in the third and last lines of the paragraph should read "1300 stokes."

Air-Cooled Cylinder-Head Design

(*Concluded from p.* 191)

and some temperature limits for types of cylinder-heads which should be regarded as danger figures?

Three very interesting lines of development were pointed out in the paper: the spark-plug cooler and shielding, the rotary nose-cowling, and automatic throttle-stops. I think that, with the high-duty engines, whether over-compressed or highly supercharged, one of the next important developments is an automatic type of throttle stop rather than to leave the throttle setting purely to the judgment of the pilot.

The spark-plug cooler with its shielding was completely described. In connection with that 2-in. water-hose test, a suggestion has been tentatively made that the test of the satisfactoriness of a spark-plug shielding, as regards ignition reliability, is that it should be sprayed with salt water for 3 hr. and the electrical characteristics be satisfactory after as well as before the test. We made a few tentative measurements in that regard but no such system has been adopted as yet.

I assume that the detailed information about the nose cowl is not available, but we should be much interested in the way it was laid out.

Thermocouple Gives Basic Indication of Danger

MR. CHILTON:—We have not subjected the spark-plug shield to a salt-water test for as long as ¾ hr., but I believe that the Transcontinental Air Transport once made a rather severe test, using two big fire hoses and continuing the test until the water removed most of the cowling.

As to head temperatures, we think there is a definite critical temperature for each head design beyond which the engine will give trouble. On our tests curves are plotted in several different ways. One of them is plotted in cylinder-head temperature against mixture strength in full-throttle operation, and other curves are plotted on the other variables. We do think that there is a definite limit beyond which you should not go with any cylinder-head. You may have to repeat the test several times with good modern heads before you actually get into physical trouble and the head goes off, as was illustrated by what happened when we set these temperature limits. Pilots are warned that they should not take the heads beyond certain temperatures, but they decide that they will see about that. Then, when the temperatures are exceeded for several hours in the ship, if the heads do not actually blow off, the pilots will tell you that you are wrong.

We believe that the thermocouple gives the basic indication of the engine condition, and if the pilot uses his head, he becomes an automatic throttle-stop. It should not be difficult to get all the pilots to do that.

CHAIRMAN ARTHUR NUTT:—An automatic throttle-stop device that is operated from the manifold pressure is now available but it does not meet all requirements, because, if a local condition in a cylinder is causing detonation, the manifold gives no indication of that. However, it is a step in the right direction. One danger is that, if the pilot becomes accustomed to depending on the device to pull the throttle back for him, and anything happens to it, then it is just too bad. Some device such as this thermocouple is probably much simpler. The simplest device that will work satisfactorily is the best device, as it is most reliable and least expensive.

Reducing Fan Horsepower and Noise

Discussion of A. D. Gardner's Semi-Annual Meeting Paper[1]

FURTHER work is needed to determine more definitely the values of the exponents of the power curves and the extent to which they are influenced by such factors as number of blades and the like, according to one discusser. Recent research work on the reduction of the horsepower which must be transmitted by the fanbelt, the reduction of fan noise and the increase in cooling efficiency which can be obtained from the fan is outlined. The need for static-pressure data is stated, and spiral-blade-fan efficiency, road power-requirements and the like are commented upon. It is stated by the author that no attempt was made in the tests to determine fan characteristics under various pressure conditions on either the suction or the discharge side of the fan.

Adequate fan space is an essential, according to other discussers, who comment also on the discharge characteristics of fans running in free air as compared with their operation in actual practice as installed for automotive work.

N. S. DIAMANT[2]:—The paper is a most welcome, complete and valuable contribution. However, its very excellence to meet our present needs throws into deep contrast its limitations. Mr. Gardner has presented groundwork which should be refined, improved and expanded. For example, the exponents of the power curves, Fig. 4, cover a range from 2.64 to 2.94. Further work is needed to determine more definitely the values of these exponents and the extent to which they are influenced by such factors as number of blades and the like. Investigations also are necessary to determine the effect of many variables such as louvers and the position of the fan with respect to the engine, radiator and other accessories. Mr. Gardner's method of reducing fan noise by changing the angular spacing of the blades is very ingenious, simple and effective. The 15 items stated in the summary are borne out by general experience and should prove very valuable for reference purposes.

Recent Research Work on Fans

R. C. SANDERS[3]:—The paper covers the fan situation from the fan-manufacturers' viewpoint, but the manufacturer is mainly concerned with driving the fan satisfactorily so as to obtain the necessary cooling, the reduction of noise being secondary. Our company's recent work on fans has divided itself into three phases which are, in order of importance, (*a*) the reduction of the horsepower which must be transmitted by the fan belt, (*b*) the reduction of the fan noise and (*c*) the increase in cooling efficiency which can be obtained from the fan. Most of our effort has been applied to phase (*a*).

When our work was begun, we had on the Chrysler eight-cylinder engine a six-blade 16-in.-diameter fan. The total load on the fan belt with this fan at 4000 r.p.m. engine speed was approximately 14½ hp. We found by experiment that equal cooling could be obtained with a four-blade 18-in.-diameter fan and that the total power required was reduced to approximately 11 hp. Further work on this problem has shown that, by increasing the diameter of the pump impeller ¼ in. and reducing the pump and fan speeds from a ratio of 1.37 to 1.24 to crankshaft speed, we were able to obtain satisfactory cooling with the four-blade 18-in.-diameter fan on an even larger engine than that on which the original six-blade fan was used. This decrease in fan speed gave a further reduction of 2¾ fan hp. so that the total reduction from the original six-blade 16-in.-diameter fan to the new speed of the four-blade 18-in-diameter fan was 38 per cent of the total fan-belt horsepower. In our opinion these results show that a still better design of fan can be made which perhaps will reduce the necessary horsepower that must be used in driving it even further and at the same time provide the desired cooling, thereby relieving some of the increasing load on the fan belt.

Regarding noise reduction, we have used the irregular fan-blade spacing described in the paper with very good results; but more research in this direction is needed. The reduction of fan speed has also helped to reduce noise.

Work has been in progress recently in the development of a more-efficient fan than the present type, but the progress is slow because of the infinite number of fan-belt shapes, blade spacings and fan diameters, as well as the great number of speeds and other conditions under which the fan operates on a car. In our opinion a very real need and a ready market exist for an automobile fan that has a low horsepower-requirement, is quiet and will deliver the necessary air for cooling. To obtain all of these qualities in one fan may be impossible, but we are sure that we shall soon be able to get more of them than we have ever got before.

Static-Pressure Data Needed

L. P. SAUNDERS[4]:—Drawing any conclusions concerning the fan efficiencies stated in the paper is impossible due to the entire lack of static-pressure data. Efficiencies can be computed only by measuring energy output from the fan, and this will be a percentage of the horsepower input. Fans are glorified or coarse-pitch screws and, in the case of a propeller-type fan, the lower the slippage is, the greater the efficiency will be, regardless of static pressure; but disc-type and blower-type fans must develop static pressure.

Static pressure is equivalent to voltage in a generator which must be raised to overcome or cause current flow against resistance, and to quote free deliveries or amperes without quoting corresponding pressures gives

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[1] The paper was published in the August, 1931, S.A.E. Journal beginning on p. 109. The author is chief engineer for the Automobile Fan & Bearing Co., Jackson, Mich. A brief summary of the discussion is printed herewith.

[2] A.S.A.E.—Consulting research engineer, Chrysler Corp., Detroit.

[3] J.M.S.A.E.—Engineer, Chrysler Corp., Detroit.

[4] M.S.A.E.—Chief engineer, Harrison Radiator Corp., Lockport, N. Y.

us nothing to work with. Airflow through a fan is caused by a pressure difference set up by moving blades that compress the air on the discharge side and cause inflow on the low-pressure side. An increase in velocity is caused by a decrease in static pressure at the discharge side, which is the probable reason why the slow-speed four-blade fan gave better cooling than did the high-speed six-blade fan. The importance of static pressure cannot be over-emphasized, and if Mr. Gardner will analyze the static-pressure figures, which no doubt he has, some of the questions that may present themselves—particularly with reference to the effect of blade widths and pitches—will be readily answered. Reference is made to an increase in efficiency with a decrease in blade width. Here again probably the static pressure is practically zero.

Spiral-Blade Fan Efficiency-Increase

The probable reason for the increase in efficiency of the spiral-blade fan as stated in the paper is to be found in the description of the air-discharge flow-characteristics described later in the text for Fig. 18, this phenomenon being due to a low-pressure area in the vicinity of the hub caused by the semi-centrifugal discharge from the long part of the blade. This condition can be corrected by fitting a disc to the back of the fan in a way similar to that used for many years by Daimler, of England. We have been endeavoring to determine the power requirement of fans on the road; but we have not been able to devote sufficient time to this project. However, the characteristics of disc and blower fans with horsepower increases for variations in static pressures are as shown in Fig. 1 herewith.

Road Power-Requirements

Two theories can be advanced concerning the road power-requirements. The first is that the airflow through the radiator core boosts the static pressure delivered by the fan and, as shown in Fig. 1 herewith, this will result in an increase in horsepower required, which may account for the increase in speed obtained, as stated in A. F. Denham's recent article on Radiator Design[5], when the fan is disconnected. The second theory is that the airflow velocity through the core on the car is so low that it does not attain the same velocity as the air delivery through the fan. We have found similar results to those of Mr. Gardner when running with and without the fan. In the latter case we find that the cooling system is very unstable; a passing car upsets the equilibrium very easily and, instead of approximately 10 miles of distance covered at constant load and speed being necessary for the system to become stable, as high as 30 miles is needed.

Concerning the airflow through the radiator, if the heat dissipation does not continually increase with airflow, the air is short-circuiting over some section of the air passage and is not convecting heat. By increasing the airflow through a core 50 per cent, we can raise the heat dissipation from approximately 5200 B.t.u. to in excess of 8000 B.t.u. per min. We assume that approximately 1 cu. ft. of air must flow through the core to dissipate 1 B.t.u. per min. Two-blade fans probably are satisfactory on small cores, due to the low resistance to airflow of these cores. Some years ago a well-known fan-manufacturer published data to the effect that a shroud decreased the fan horsepower 16 per cent, with an increase in free delivery of 20 per cent.

[5] See *Automotive Industries*, June 13, 1931, p. 915.

Summing up the entire situation, the cooling system at present, so far as airflow is concerned, is in much the same category as that of the radiator. From the fan manufacturer's viewpoint, what is the loss in air delivery on the car compared to wind-tunnel results? From the radiator manufacturer's viewpoint, due to the loss in airflow between the heat dissipator and the car, how much excess capacity should the radiator have to provide adequate performance? In other words, is providing a 6000-B.t.u.-per-min. radiator to take care of a 4000-B.t.u.-per-min. engine necessary because of this loss in airflow?

Pressure Considerations Important

A. D. GARDNER:—No attempt was made in the tests described in the paper to determine fan characteristics under various pressure conditions on either the suction or the discharge side of the fan, but the discussion rather was limited to what would happen when various features, such as diameter, number of blades, projected width, blade curvature and the like, were changed. A sufficient number of variables already entered into the picture without the introduction of the wide range of pressures found on the various cars, so that tests were made with only normal core restrictions on the suction side of the fan and with practically free delivery.

Considerations of pressure are of utmost importance in their effect on fan efficiency. When a fan is mounted on the engine, it is at once subjected to a set of condi-

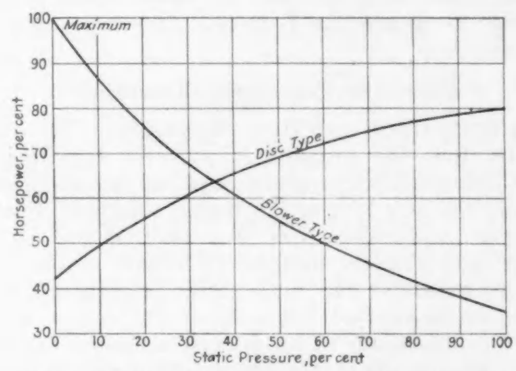


FIG. 1—CHARACTERISTICS OF DISC AND OF BLOWER FANS WITH HORSEPOWER INCREASES FOR VARIATIONS IN STATIC PRESSURES

tions that invariably reduce its efficiency. Air is not permitted to flow freely to the fan, which decreases the delivery from it appreciably; but the horsepower consumed by it decreases only slightly. If the fan is mounted low in front of the engine, its blades may deliver but little air in passing through the lower portion of their path, while useful work may be done only by the upper segment of the fan. If the exit openings from the engine compartment are limited in area, the resistance causes static pressure to be built up behind the fan, which decreases both its total and its unit output.

In general, motor-car manufacturers are now providing more openings for the air to escape from the engine compartment, which permits a fairly free fan discharge. But as cooling requirements become more difficult to meet and frontal areas are reduced, the radiator manufacturers are installing denser and thicker cores which have greater heat-dissipating capacity for a given airflow, but which also have such high resistance that the

volume of air which the fan can draw through the core may be reduced considerably. The fan designer is then called upon to covercome this imposed handicap of restricted fan inlet and increase the airflow so as to equal the flow through a thinner or less dense core. This he may or may not be able to do, depending upon the amount of the restriction imposed and other limiting features, such as space available and permissible noise. The greater the pressure drop across the core is, the greater is the handicap which the radiator imposes on the fan so that part, at least, of the capacity of the thicker and denser core may be lost due to the lower rate of airflow through it.

While the net result of this set-up may be a gain in capacity to dissipate heat, we believe that some consideration should be given fan requirements if maximum efficiency of both units is to be obtained. To increase core efficiency at the expense of fan efficiency should not be the logical procedure.

Considerations of pressures are of utmost influence on fan performance, but they are present only to the extent that the flow of air to the fan is interfered with by thick or dense cores or the free discharge of air from the fan by static pressure in the engine compartment. Two things apparently are needed to assure that both radiator and fan operate at maximum efficiency; (*a*) closer cooperation between radiator and fan manufacturer and (*b*) a very extensive investigation of the behavior of conventional-type fans under a wide range of pressure conditions, followed by development of suitable types to assure the required airflow against high static pressures.

Adequate Fan-Space Essential

LOUIS SCHWITZER[6] AND H. E. WINKLER[7]:—We wish to emphasize that the problem of suitable fan-design as regards noise and horsepower required is one that was solved successfully by the fan maker long ago, but that its practical application has been handicapped in most cases by the chassis designer. Where undue noise exists and excessive fan horsepower is required, insufficient space is allotted for a satisfactory fan installation. The importance of an adequate cooling system is obvious. It depends to a great extent upon the fan installation, and the needed space must be provided just as for any other unit that is essential for a satisfactory automotive design. A successful engine-design depends upon the space allotted for valve sizes and bearing length; but, unfortunately, the general assumption seems to be that an efficient fan installation can be made in zero space. What does it matter if an extra inch of wheelbase is demanded to accommodate the fan satisfactorily, when the entire operation of the car depends upon it? Our experience has been that, in practically every case in which difficulties were met, if an extra inch had been available for the fan installation these could have been avoided by economical means. More efficient blades of greater width set at flatter angles and running at slower speeds cause less noise and require less horsepower, and sufficient space provided for an adequate drive results in longer fan-belt life. The space between the fan and the engine crankcase, the free space available underneath the hood and the outlets through and underneath it very largely govern the fan performance.

[6] M.S.A.E.—President and chief engineer of Schwitzer-Cummins Co., Indianapolis.

[7] J.M.S.A.E.—Engineer, Schwitzer-Cummins Co., Indianapolis.

The discharge characteristics stated by Mr. Gardner are true in free air, but they assume an entirely different form in actual practice with fans installed for automotive work. Discharge characteristics change when working against static pressures, as is the case at the higher car-speeds. Our experience has shown, particularly through laboratory tests, that high initial air-velocities do not change the horsepower requirements to a great extent, but they do increase them. Modern radiator cores having high static resistances reduce air deliveries to the fan and therefore its horsepower requirements; but if air is blown through this core against the fan, the discharge behind the fan is increased and so is the fan work, which necessitates greater fan horsepower. Set-ups of this kind were made in our laboratory up to 60 m.p.h. initial air-velocities to prove this contention.

General Experience Cited

We have never found that the increase in air delivery is proportional to the increase in diameter as indicated in Fig. 7 of the paper. We can check the horsepower versus fan-diameter curves shown in Fig. 8, but we find that the air-delivery versus fan-diameter curves of Fig. 7 are not straight lines but curves similar to the horsepower versus fan-diameter curves shown in Fig. 8. A very decided gain in cooling efficiency is nearly always obtained with an increase in fan diameter. In one instance the cooling on a well-known automobile was increased from 5 to 8 deg. fahr. per fan hp. merely by increasing the fan diameter ½ in.

In view of the fact that the atmospheric horsepower delivered by a fan is such a small part of the power absorbed by the fan, the tests which we have conducted on blade shapes—particularly on fans of the larger diameters—indicate that the vacuum created back of the blades is responsible for the greater part of the power absorption by the blades. Blade shapes that reduce the magnitude of the vacuum back of the rotating blades invariably raise the fan efficiency. We have developed combinations of angular spacing and blade widths which give very desirable airflow results in projected widths up to 3½ in., which is as much fan space as is ever available in automotive work. Probably the most enlightening method of explaining fan performance in its relation to blade shape, projected width and angle of twist is a close study of the performance characteristics of fans working against varying degrees of static resistance. The fact must be kept in mind that the velocities obtainable through a radiator core are dependent upon the ability of the fan to produce pressure-drops across the core.

Fan-Problem Difficulties

We find that cylinder-head pump-installations cause the most difficult fan problems. High fan-and-pump shaft-speeds are usually needed to attain satisfactory water-distribution conditions. The fan center is low and the fan diameter is sometimes limited. Each of these three points has a detrimental effect on fan efficiency and tends to increase fan noise. If this design embodies true economy is very questionable, because the shortcomings of the fan and the water-pump installation must be compensated by the radiator core. In addition to the objections to cylinder-head pumps, we find that this design is the worst offender in causing the throwing-off of fan blades. This is due to the rapid

wear often experienced with the wet bearing on the pump assembly, which permits vibrations in the pump shaft that cannot be absorbed in the fan-blade assembly because of the gyroscopic couple which resists displacement from its plane of rotation. The result is that the blades remain in their own plane and the fan center is deflected.

We made our first fan having unevenly spaced blades, several years ago, by removing two opposite blades of a six-blade fan. Our endeavor at the time was to eliminate the "beat" in one of the current automobiles, but we found that the beat was not audibly affected. Since then we have conducted additional research from which we have concluded that, in general, fan-drive ratio is the only factor that has an important bearing on this point.

Oil Consumption as Affected by Engine Characteristics

(*Concluded from p. 214*)

would make necessary the use of the three grades within the period of one week. The recommendation of three grades necessitates the use of two oils between atmospheric temperatures of 20 and 40 deg. fahr.

Instead of following the car manufacturers' recommendations to use oils of three different viscosity numbers, it would be far better to fix the range of operation of a motor oil by using the temperature at which the oil reaches 50,000 Saybolt sec. viscosity as the low-temperature limit and the temperature at which it drops to 60 Saybolt sec. as the high-temperature limit.

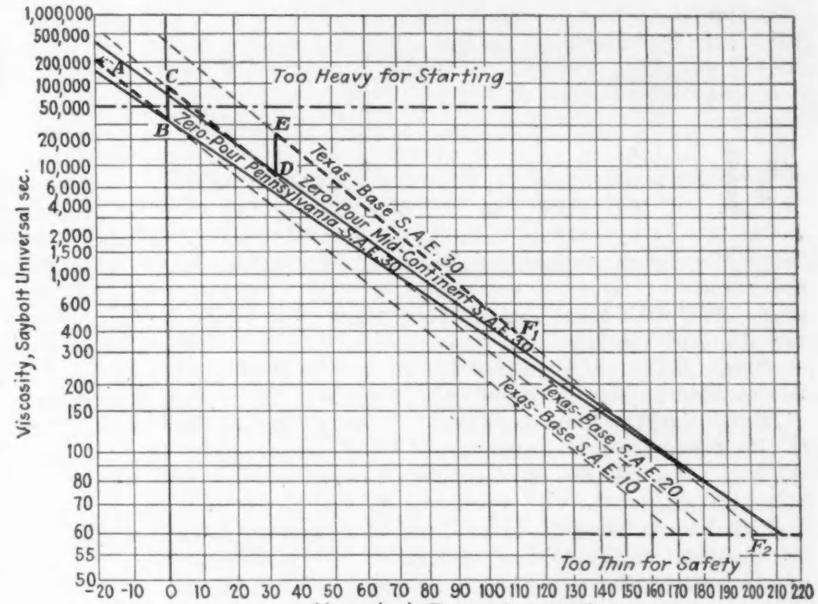


FIG. 18—COMPARISON OF TEMPERATURE-VISCOSITY SLOPE OF THREE GRADES OF TEXAS-BASE OIL WITH ONE GRADE OF ZERO-POUR-TEST DEWAXED PENNSYLVANIA-BASE OIL

Using Texas-Base Oil and Following the Recommendations of Some Car Makers Would Require S.A.E. No. 10 from —20 to 0 Deg. Fahr. Atmospheric temperature and S.A.E. No. 30 at Temperatures above 32 Deg. Fahr. The Slope of Viscosity Change of Pennsylvania-Base Oil Is Less Steep and This Oil Is Less Viscous at Below-Freezing Temperatures and Sufficiently Viscous for Safety at Atmospheric Temperatures up to 120 Deg. Fahr.

Standardization of Operations

C. E. WILSON, Vice-President of General Motors Corp., had the following to say at the last National Production Meeting regarding the designing of similar parts so that similar operations are done on them: "While it usually is impossible to make parts absolutely the same for similar lines of cars or whatever the product of a plant may be, it usually is possible to make the parts that are similar from the same kind of material and to design them in such a way that the factory experience on one part readily applies to another part. The same machine-tool, with perhaps a little different tooling, can be used to produce the part. This sort of standardization is, I am sure, one of the important factors that has helped us all to build up volume production of high-quality interchangeable equipment."

Mr. Wilson also said that the application of electric welding is well worth the serious study of anyone who is responsible for production and processing methods in automobile plants. In many cases it has been found possible to substitute, with more satisfactory results, simple, light and cheap stampings that are welded together for machined castings and complicated screw-machined parts.

Milling with Tungsten and Tantalum-Carbide Cutters

Milwaukee Production Meeting Paper

By Frank W. Curtis[1]

APPLICATION of tungsten carbide to milling is said to have lagged because results did not seem to justify the cost until modified cutter design was developed. Cutter angles that have proved satisfactory are given, and designs of cutters are shown.

Rigidity in cutter, machine and fixture is emphasized as an important requirement, and numerous examples of speeds and feeds are cited. Successful use of tantalum carbide for milling steel is reported, and the paper concludes with a list of suggestions for the successful introduction of milling with these two cutting materials.

MILLING is, without question, one of the most outstanding applications of tungsten carbide; but this work has not kept abreast of other metal-cutting operations with the same material, largely because early experiments failed to show consistent results and the cost did not seem justified. Cutter designs used with other metals were followed in these attempts, and the machines were not suited to tungsten carbide. Either of these conditions will prevent tungsten-carbide cutters from proving satisfactory.

Division of the total work among several cutting teeth is the reason for the success of tungsten carbide in milling. Success depends entirely upon rigidity; lack of rigidity is by far the worst evil with which tungsten carbide has to contend. Weakness in either the cutter, the machine or the fixture will nullify the effectiveness of strength in the other two.

Inserted-blade milling-cutters, solid and rigid in construction, can be readily designed to secure the full benefits of tungsten carbide. They are highly successful, and their use will unquestionably become very broad in the near future. Several examples of such cutters which have proved satisfactory for milling metal of virtually all kinds are illustrated in Fig. 1. Among these cutters are some that have been used to remove from 1/16 to 3/16 in. from cast-iron parts at feeds greater than 50 in. per min.; bronze, up to 75 in. per min.; and aluminum, up to 100 in. per min. These cutters are made so that any blade can be replaced, if the tungsten-carbide insert should become damaged, without affecting the remaining blades.

[1] Research engineer, Kearney & Trecker Corp., Milwaukee.

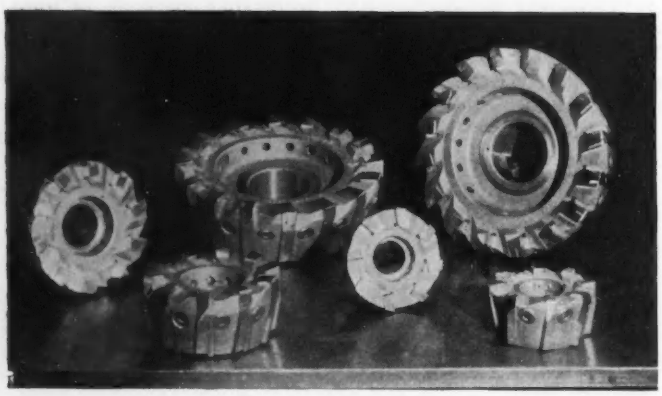


FIG. 1—ASSORTMENT OF INSERTED-BLADE TUNGSTEN-CARBIDE MILLING-CUTTERS

Solid, plain side-cutters and end-mills have been used with marked success, but their application is somewhat limited because the replacement of the damaged insert is more of a problem when they are brazed solidly to the steel body. The temperature required for brazing a new tip in place tends to loosen other tips, so that it is often necessary to rebuild completely a solid cutter when one of its tips becomes damaged.

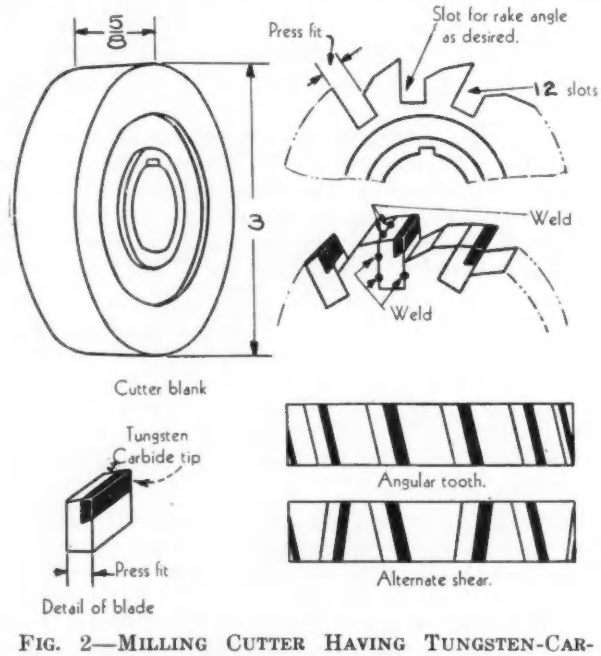


FIG. 2—MILLING CUTTER HAVING TUNGSTEN-CARBIDE-TIPPED BLADES TACK-WELDED IN PLACE

Tungsten-carbide-tipped blades can also be tack-welded after being pressed into slots in a cutter body, as shown in Fig. 2. One or more blades of this sort can usually be replaced without much difficulty if necessary. The blades are milled out and the tips are brazed in place The cutter body is slotted at the desired angle, the slot width making the blade a press fit.

Three outstanding requirements for the design of tungsten-carbide milling-cutters are: (1) ample strength and rigidity in the body and the blades; (2)

solid support for the blades, directly back of their cutting edges, and (3) positive locking of the blades.

The blades should be heavy, to withstand fast feeds, and it is a decided advantage to have the bodies hardened to resist wear. Since rigidity is so important, the blades should be supported as close as possible to the cutting edges. Extending the blades beyond the face of the body is not permissible, as it will cause vibration that may result in cracking or breaking the tips. No attempt should be made to apply tungsten-carbide tips to old cutter bodies.

Suitable machine-tools are recognized as one of the first requirements for the successful use of tungsten carbide, and this need is important for milling. The contrast between the speeds and feeds for this material and for other tools is so great that milling-machines of the older type obviously are not adequate, and they may not provide the strength and rigidity which are so necessary. The design of milling-machines has changed much during the last decade, and it is false economy to try to "get by" with equipment that has become obsolete. A machine-tool is obsolete when it fails to earn the profits that can be obtained with a new

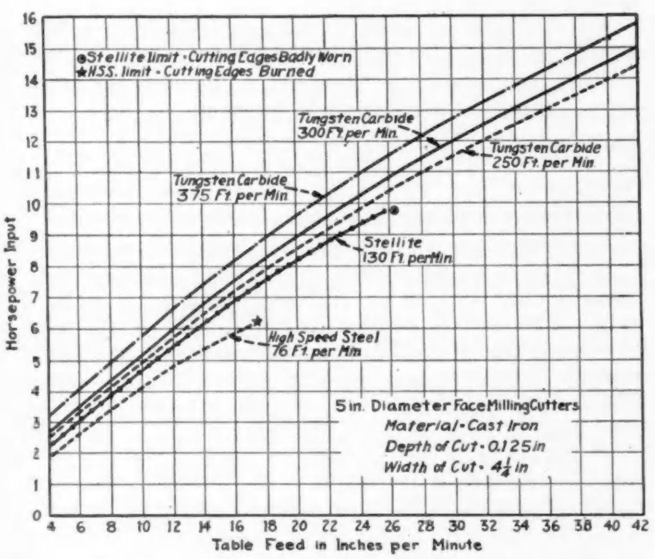


FIG. 3—HORSEPOWER REQUIRED FOR MILLING WITH HIGH-SPEED-STEEL, STELLITE AND TUNGSTEN-CARBIDE CUTTERS

machine; machines designed for high-speed steel cannot compete with those that are basically designed for tungsten carbide.

If an existing machine is in perfect condition and its size and style seem to be suited to the purpose, there is no serious objection to attempting the use of tungsten carbide in it. If, upon trial, the machine shows a tendency to chatter, it will be best to stop immediately. If the cause of the chatter cannot be removed, it is best to abandon further attempts. Some of the old machines will work satisfactorily at relatively low speeds, but not when the spindle and table are operating at speeds and feeds that are suited for tungsten carbide.

Horsepower Requirements

Tungsten-carbide milling-cutters undoubtedly require more power than other cutters, because of the increased spindle speed. Stellite consumes more power than high-speed steel, because it cuts faster, and tungsten carbide requires slightly more power still. The difference in power requirements may be seen by reference to the curves in Fig. 3, representing cuts with 5-in. inserted-blade face-milling cutters made in cast iron 4¼ in. wide, to a depth of ⅛ in. The curve for high-speed steel operating at 76 ft. per min. ends at the point where the table feed is 17 in. per min., when the cutting edges of the teeth burned and wore away badly. The Stellite cutter, running at 130 ft. per min., was operated up to table feeds of 26 in. per min., at which point the edges of the blades wore away badly. This might be expected, as the feed per tooth was approximately 0.022 in., which is somewhat more than is recommended for this cutting material. The tungsten-carbide cutter was operated at speeds of 250, 300 and 375 ft. per min., as indicated on the curves, operating at table speeds beyond 45 in. per min. without harm to the cutter. Many other tests were conducted with larger and smaller cutters and varying cuts, and the comparative results were very similar.

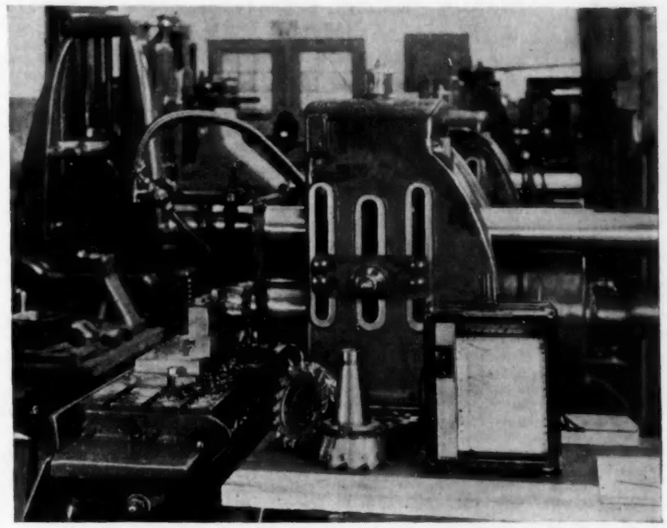


FIG. 4—MILLING-MACHINE WITH RECORDING METER FOR DETERMINING POWER INPUT

One of the milling-machines that was used for determining the horsepower is the Milwaukee Simplex, shown in Fig. 4, arranged for spindle speeds from 15 to 1000 r.p.m. and table feeds from ½ to 100 in. per min. The horsepower computations are checked by the Esterline graphic wattmeter shown, which records the actual power input.

Depth of Cut

Scale on an ordinary iron casting apparently can be machined with tungsten carbide almost as easily as the metal underneath, because of the extreme hardness of the cutting material. Machining allowances can therefore be reduced from ⅛-¼ in. to 1/16-⅛ in. Pattern changes must be made to secure the full benefits.

Three advantages result from such a change: (*a*) saving in material, (*b*) reduction in the horsepower-hours required per square inch of surface to be machined, and (*c*) an increase in feed without danger of overloading the machine. Fig. 5 represents the results in machining a cast-iron surface 5¼ × 11½ in., having a cored center as shown. The depth of cut with the former tools was approximately 3/16 in., the table feed was 20 in. per min., and the horsepower approximately 12½. The amount of metal removed was 7.8 cu. in. or

TABLE 1—DATA ON MILLING OPERATIONS WITH TUNGSTEN CARBIDE

Name of Part	Material	Size, In.[a]	Depth of Cut, In.	Cutter Speed, Ft. per Min.	Table Feed, In. per Min. Former	Table Feed, In. per Min. Present	Cutting Time, Sec. per Piece
Pump-Body	Cast Iron	2⅝x3	1/16-3/32	280	12.5	32.5	7[b]
Chain Cover	Cast Iron	7½x7½	⅛[c]	288	10	26[c]	20
Flywheel Housing	Cast Iron	8x8	⅛	297	8	26	20
Gear-Case Cover	Cast Iron	1½x12¾	⅛[c]	280	10	26[c]	30
Pump-Body	Cast Iron	3⅝x4	⅛	305	..	32.5	20
Exhaust Flanges	Malleable Iron	4⅛x5¾	3/32	375[d]	35	42.5[d]	10
Manifold for Small Four-Cylinder Engine	Cast Iron	2x19⅛	1/16	345	..	52	30[e]

[a] Over-all dimensions of surface milled, area reduced by rounding and/or coring.

[b] Six pieces milled at one operation.

[c] Further increase in speed can be obtained by a pattern change that will reduce the depth of cut necessary.

[d] A cutting coolant is used.

[e] Former time for disc grinding was approximately 45 sec. The chief item of economy is the saving in tool cost, which was more than 500 per cent greater per piece for grinding-wheels than for tungsten-carbide cutters.

2.02 lb. Reducing the depth of cut to 3/32 in., which is ample for tungsten carbide, the feed could be increased to 42 in. per min. with 295 ft. per min. cutting speed and the same horsepower as before. The saving in metal was 1 lb., costing 6½ cents. The outstanding advantage, which is typical of many milling operations, is that the feed can be increased 112 per cent without increasing the horsepower. Better control of the size of the foundry output is advantageous with reduced finish allowance, both to assure cleaning the casting and to prevent excessive cuts which might stall the machine and possibly cause damage to the cutter.

Other advantages are that the accuracy is often increased because of reduced cutting pressure and a slight reduction in feed per tooth, the heat is reduced, and there is less danger of chipping or breaking the edges of castings. Sometimes also roughing and finishing operations can be combined or annealing operations eliminated. Properly applied, tungsten-carbide cutters will operate 2 to 10 times as long between grinds as other cutters. Several examples of production secured from tungsten-carbide cutters are given in Table 1.

Modifications in Tool Design

Quick-operating fool-proof clamping devices are highly essential with tungsten-carbide milling-cutters; traditional methods of applying straps, bolts, nuts and

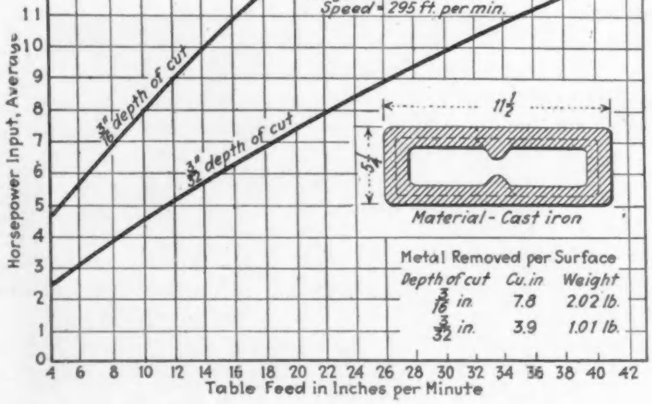


FIG. 5—POWER REQUIREMENTS WITH DIFFERENT DEPTHS OF CUT

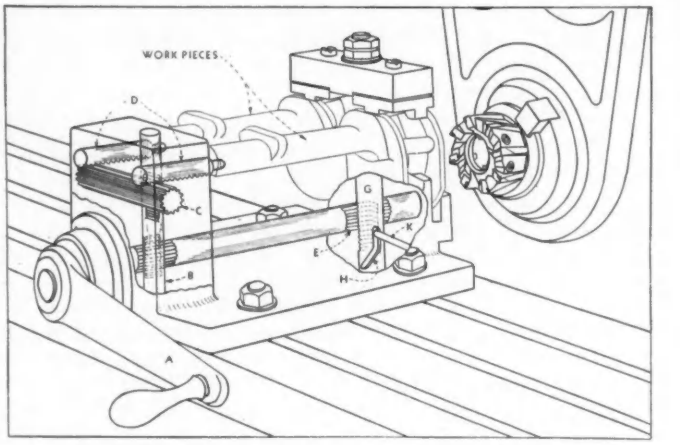


FIG. 6—MILLING-FIXTURE FOR PUMP BODIES

This Fixture Aligns Both Pieces Accurately and Clamps Them Securely with a Single Movement of the Operating Handle

screws are doomed. The loading time must be lessened in many cases to obtain the full benefits of the higher speed of the cutters, so that fixtures of entirely new design must be provided.

An example of such a device is shown in Fig. 6, which is designed for holding two cast-iron pump-bodies in face-milling the ends. The clamping devices are all actuated by a slight movement of the operating handle. The parts are milled at a cutter speed of 325 ft. per min. With a table feed of 32½ in. per min., the depth of cut is 1/16 in., the cutting time is 20 sec. and the total time 25 sec. for two pieces.

The remark is often made that tungsten carbide cannot be used to advantage on certain jobs because the operator cannot reload quickly enough to make any gain. This indicates that tool engineering will have to go a step further. In an actual case, a fixture of conventional type would permit production of approximately 65 pieces per hr. By the addition of quick-operating clamps at an extra cost of $275, the output was increased to 80 pieces per hour. The additional cost of the fixture is quickly recovered on this basis. Existing fixtures can be used in many cases, while in others the fixtures will need to be replaced for the rigidity that is so essential.

Experience has shown that the rake and clearance angles of tungsten-carbide turning-tools should be slightly less than those of high-speed-steel tools. The same is true of milling-cutters. Details of a typical cutter designed for machining soft or medium cast-iron are shown in Fig. 7. The angle at the periphery should be sufficient to clear the work, so that the heel of the blade shall not drag; 5 deg., as shown, usually is sufficient. The rake angle can be reduced from 3 to 1 deg. and the face angle increased from 6 to 8 deg. without material change in the cutting efficiency or life, but the angles shown have proved successful. The same angles can be used for milling malleable iron; but aluminum and yellow brass require greater face angles of 10 to 15 deg., and the bottom clearances should be approximately 4 or 5 deg. for brass and 5 or 6 deg. for aluminum.

Tantalum Carbide for Milling Steel

Many attempts have been made to machine steel with tungsten carbide; but these have not been entirely successful, in spite of the many improvements that have been made in the hardness and toughness of the tool

material, because of the strong affinity between it and steel which causes a crater action so that the tip tends to break away. This difficulty has been largely eliminated by the recent introduction of tantalum carbide, which has characteristics similiar to those of tungsten carbide but has not the same affinity for steel. This lack of affinity makes the brazing more difficult.

Tantalum carbide has proved satisfactory for milling steel. Tests so far indicate that the cutting speed can be increased approximately 100 per cent over that with high-speed steel. An actual example is the milling of the gear blanks shown in Fig. 8, forged from S.A.E. No. 3140 steel, from each side of which 1/16 in. must be removed. The steel is tough and hard and is ordinarily machined at 75 ft. per min. with a feed of 6½

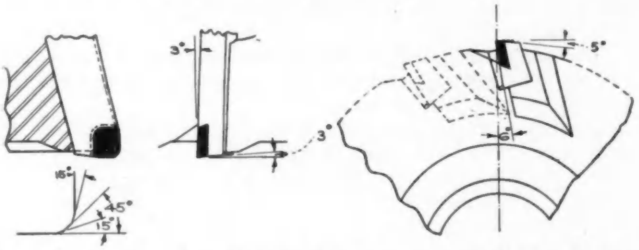


FIG. 7—CUTTER ANGLES RECOMMENDED FOR MILLING CAST IRON

in. With a tantalum-carbide cutter, the speed has been increased to 170 ft. per min. and the feed to 14 in. per min.

Observations on Milling with New Materials

Additional suggestions regarding the use and applications of tungsten and tantalum carbides to milling-cutters are as follows:

(1) Begin your experience with milling flat surfaces from which a uniform amount of material is to be removed. Analyze each milling operation carefully before applying cutters of the new type, and extend their application gradually to the more difficult operations.

(2) Endeavor to make each application a success by avoiding too fast speeds and feeds at first. These are determined by the depth of the cut, the amount of metal to be removed, the type and hardness of the material and the nature of the cut.

(3) Give full instruction to the operators. They should already be familiar with the characteristics of these metals; if not, the time required to explain their nature and advantages will be well spent.

(4) Do not try to obtain maximum results on the first cut. Run the cutter somewhat slower and with less feed than the ultimate expected. If all goes well, first the cutter speed and then the feed can be increased gradually.

(5) Do not allow the spindle to stop while the feed is engaged. If the machine is to be stopped, first throw out the feed and let the cutter run for a few moments before disengaging the spindle clutch. Failure to observe this precaution will cause shock which is likely to set up excessive strains and may result in breakage of the inserts.

(6) Do not try to set up an endurance record; if the cutting edges appear to be slightly worn, they should be honed, perhaps several times between grinds. The cutter should be sharpened as soon as the cutting edges are slightly rounded over. No more than 0.001 in. of material should be removed at one grind. Be sure that the grade and type of wheel are correct.

(7) Use only a grinding-machine that is in good condition. The condition of the grinding-machine is as important as that of the milling-machine.

(8) Inspect the cutter before setting it in service after it is ground. A suitable gage or fixture should be provided for this purpose and used with an amplifying type of indicator. The faces of the blades should be square within 0.0005 in., and the periphery should not run out more than 0.002 in.

(9) Because of the cost of these cutters, they should be handled as carefully as a micrometer or other precision instrument. Do not allow them to be dropped or knocked about carelessly. Suitable storage space should be provided in the tool-room or crib, and individual boxes are recommended; all operators and tool-crib attendants should be instructed to handle the cutters with care.

(10) Use only a milling-cutter which is suited for the material to be cut; a cutter designed for milling cast iron will not work satisfactorily on steel or copper.

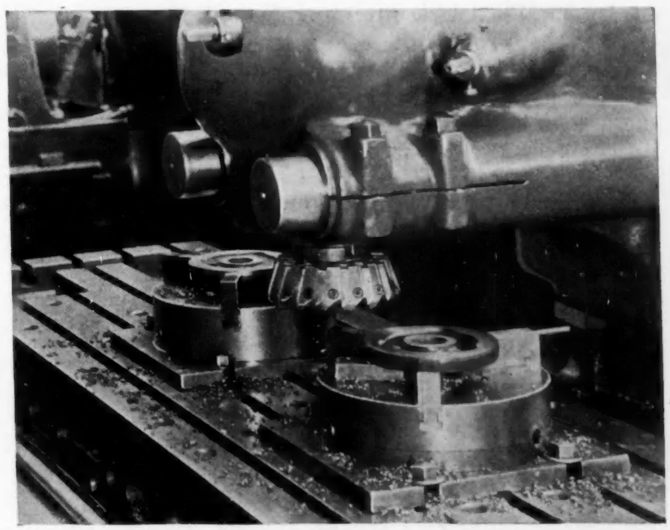


FIG. 8—FACE-MILLING ALLOY-STEEL GEAR-BLANKS WITH TANTALUM-CARBIDE CUTTERS

(11) Check the power input with an ammeter or wattmeter when increasing the speed and feed of a machine, to avoid overloading the motor. The motor may be overloaded for a short time without harmful effects, but not constantly.

If these suggestions are followed, good results can be obtained from the use of tungsten and tantalum-carbide milling-cutters. However, a slight amount of neglect is likely to cause poor results or dissatisfaction. The use of these materials is different from that of high-speed steel and other cutting materials, although not more difficult. If correct procedure is followed, surprising results can be attained.

Nitriding in Industry

By J. Muller[1]

Indiana Section Paper

STEEL for nitriding must be held to close limits in the essential elements such as chromium, molybdenum and aluminum, and the material should be heat-treated and drawn to limits that are relatively hard for machining to provide a core of sufficient strength to support the case.

The temperature of nitriding affects both the surface hardness and the hardness gradient within the case, the maximum hardness being in inverse ratio to the temperature of the reaction. The effects in hardness both at the surface and at various depths in the case under different conditions are represented by graphs.

Active circulation of the ammonia in the furnace promotes uniformity of the product. A furnace designed to give reversing circulation is described and illustrated. The material selected for the lining of the furnace must be such as not to interfere with the reaction between the ammonia and the material under treatment.

The advantages of a new duplex method of treatment, in which the work is done at two different temperatures, are mentioned.

Questions in the discussion led to the statement that new types of steel suitable for nitriding are under development but only one type is now recognized as suitable. Experiences were given in regard to distortion or growth of the metal during nitriding. References were made to continuous and other types of nitriding furnaces suitable for large production.

COMMERCIAL nitriding has as its ultimate aim the production of extremely hard surfaces on finished parts made of suitable steel, to obtain all the advantages inherent in high hardness without subjecting the finished parts to complex heat-treatment.

Nitriding is a chemical process in which the reaction between a nitriding steel and ammonia takes place at certain elevated temperatures, producing a hard case on the surface of the steel where the nascent nitrogen, made available through the dissociation of ammonia, combines with the steel to form certain nitrides. The iron nitrides produced in nitralloys do not impart harmful brittleness, such as we associate with the formation of nitride needles in other steels.

Dr. Adolph Fry, to whom we are indebted for the practicability of the process, concluded from careful and methodical researches that nitriding could best be done at temperatures ranging from 875 to 1050 deg. fahr. The consistency of the results obtained in the laboratories, coupled with the advantages from the low temperatures of the process, stimulated much interest throughout the metal world. Steel makers and certain manufacturers were quick to recognize the advantages of a material possessing great hardness which could be sustained at high temperatures.

Like every new commercial process, nitriding required a great amount of work to adapt it to wide-spread use in industry. Development at first was on a hand-to-mouth basis and involved perplexing problems, the same as when stainless steel or any other new product was introduced. Correct appraisal of the situation led to close cooperation in the study of the troublesome details of the process, which has resulted in the present knowledge and the progress in the use and proper allocation of nitrided steel in industry.

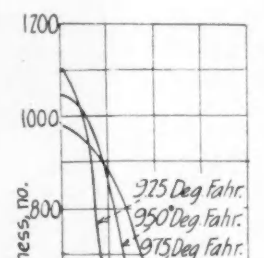


FIG. 1 — EFFECT OF NITRIDING TEMPERATURE ON SURFACE HARDNESS

Hardness at the Surface and at Points Below the Surface Is Indicated in the Three Curves after Full-Load Treatment (300 Lb.) for 24 Hr. at the Temperatures Indicated

Difficulties experienced with the nitriding process can be divided into three classes, as follows: (a) manufacturing and heat-treating the steel, (b) design and service life of nitrided parts and (c) the nitriding operation. These problems will be reviewed briefly, and most of this paper will be devoted to the nitriding process.

Requirements for Material Are Strict

Steel makers have devoted much time and energy to the development of new aluminum-alloy steels, the most widely known of which is Nitralloy. The chemical composition of these steels may vary somewhat, but such essential elements as chromium, molybdenum and aluminum are held within close limits. After learning to melt, pour and roll a steel containing 0.9 to 1.3 per cent of aluminum, the steel makers proceeded to improve both the chemical and physical properties of the steel.

The state of the material before nitriding has sometimes been ignored by makers and users of Nitralloy as an influencing factor in the ultimate product. Careful researches led to the conclusion that nitriding steels should be heat-treated and drawn to machinable hardness, the accepted limits being 180 to 260 Brinell-hardness number. The structural changes produced in Nitralloy by heat-treatment improve its nitriding characteristics.

The early manufacturer of nitrided parts

[1] Development engineer, Leeds & Northrup Co., Philadelphia.

was confronted with problems similar to those of the steel maker, to which were added the responsibility of substituting Nitralloy for stainless or other steel in his particular product. The major part of the failures experienced were due to lack of uniformity of the case, to poor structure of the material and to decarburized surfaces and distortion after nitriding.

The life of nitrided parts under various service conditions is still unknown, because the process is so recent. Laboratory tests for properties such as corrosion, erosion and wear do not always duplicate service conditions accurately enough to predict the true service life of the parts.

Manufacturers found it desirable to keep certain sections, such as threads, from being nitrided. Nickel plating and tinning were found to be the best means for doing this. When tin is used to protect the surfaces, care must be taken to prevent an excess of tin remaining on the work and to keep the work free from acid.

The problems of the maker and user of Nitralloy are closely allied to the correct application of the nitriding process, which includes many variables that must be controlled closely if it is to be successful. The main factors influencing the process and the reactions are: (*a*) the temperature at which the work is done, (*b*) the time during which the reaction proceeds, and (*c*) the rate and manner of flow of the active chemical. The process is not considered to be very difficult, provided that close control of these three variables is maintained.

Effects of Temperature and Time

Temperature has a two-fold influence upon the resulting case, affecting both the surface hardness and the

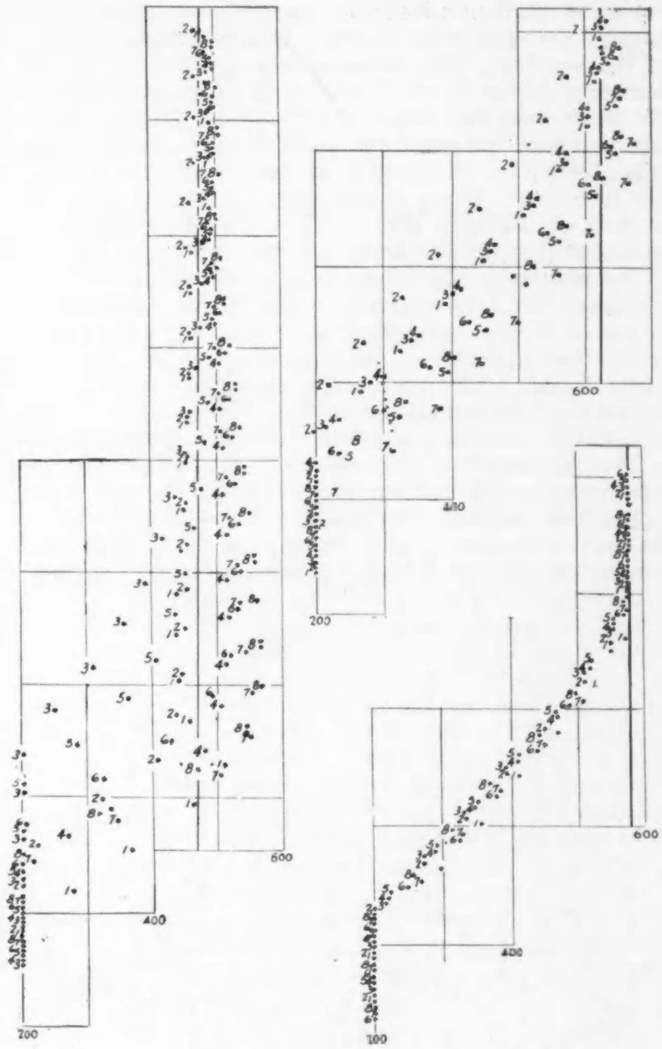
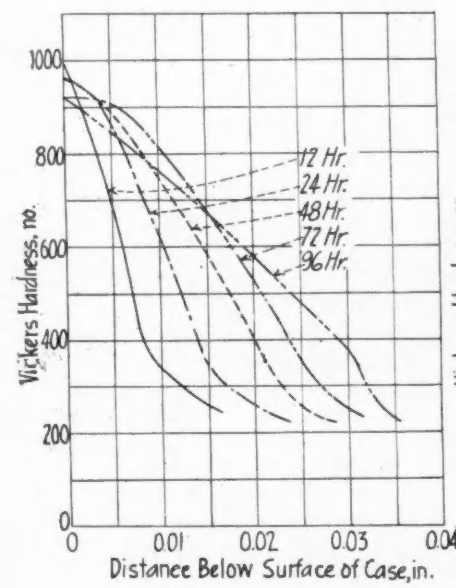
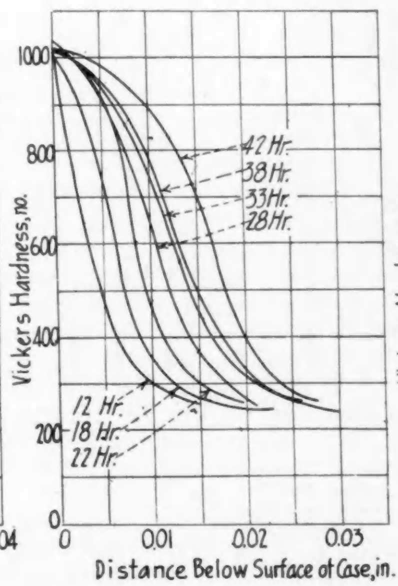
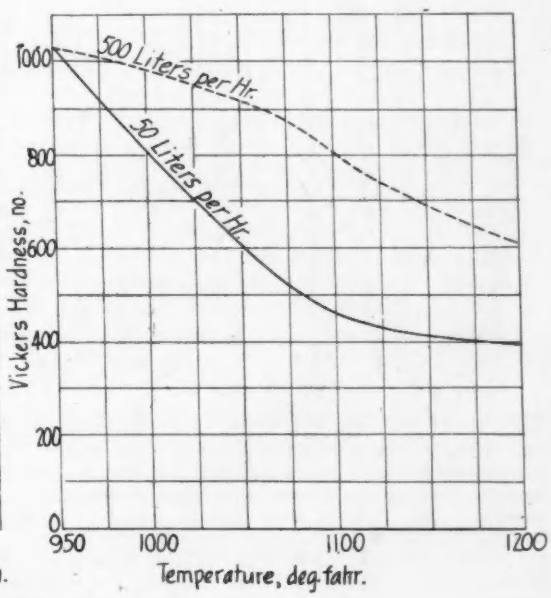


FIG. 2—TEMPERATURES AT DIFFERENT POINTS DURING THE HEATING PERIOD (CHARTS AT THE RIGHT)

Temperatures in the Graph at the Left Were Observed in Box-Type Heating; Those in the Upper-Right Graph, in Direct Convection-Heating; and Those in the Lower-Right Graph, in Reversed Convection-Heating







EFFECT OF TIME ON SURFACE HARDNESS

Hardness at the Surface and at Points Below the Surface after Treatment for Different Periods Is Indicated in the Various Curves

FIG. 3—FULL-LOAD TEST (300 LB.) AT 975 DEG. FAHR.

FIG. 4—LIGHT-LOAD TEST (10 LB.) AT 1000 DEG. FAHR.

FIG. 5—EFFECT OF RATE OF AMMONIA FLOW ON HARDNESS

hardness gradient within the case. The maximum hardness of the case is in inverse ratio to the temperature of the reaction. The three curves of Fig. 1 show the hardness at the surface and at various depths below the surface of the case after 24 hr. of dense full-load treatment at temperatures of 925, 950 and 975 deg. fahr., including the range commonly used in commercial nitriding. Those curves make it evident that uniformity of hardness throughout the load depends upon uniformity of temperature.

The process is carried on in a closed container in the absence of air. The heating of the charge can be either by conduction or by convection or both. Temperatures prevailing in ordinary box-type heating, in direct or non-reversed, and in reversed-convection heating are shown for comparison in Fig. 2. These charts were obtained by placing a number of checked thermocouples in the charge. They tend to show the spread of temperatures during heating and after the control point is reached, indicate considerable over-shooting above the control temperature in some types of heating and demonstrate the possiblity of non-uniformity in temperature wherever special precautions are not taken.

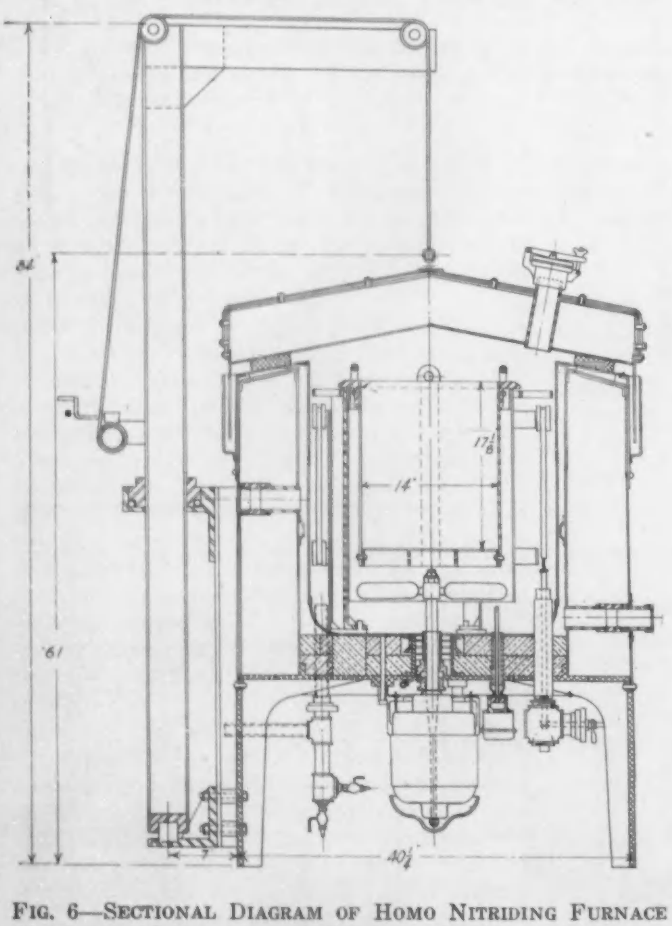


FIG. 6—SECTIONAL DIAGRAM OF HOMO NITRIDING FURNACE

The Work Is Placed in the Container in the Center. Ammonia Is Introduced Alternately through the Large Pipe in the Lid and the Smaller Pipe in the Lower Left Corner, the Motor-Driven Fan below the Work Being Reversed at the Same Time. The Air-Cooling Inlet-Pipe Is Shown in the Left Wall out of Its Position, and the Air-Cooling Outlet-Pipe in the Right-Hand Wall. Heat Is Supplied by Electrical Units Shown Surrounding the Work Container and Radiation Shield, the Lead-In Wires Passing Through the Fitting Shown at the Lower Right Corner. A Thermocouple for Controlling the Temperature Is Located Just Under the Fan in the Path of the Treating Gases, with a Lead-In between the Fan Motor and the Main Electrical Connection. The Lid Is Closed with an Oil Seal

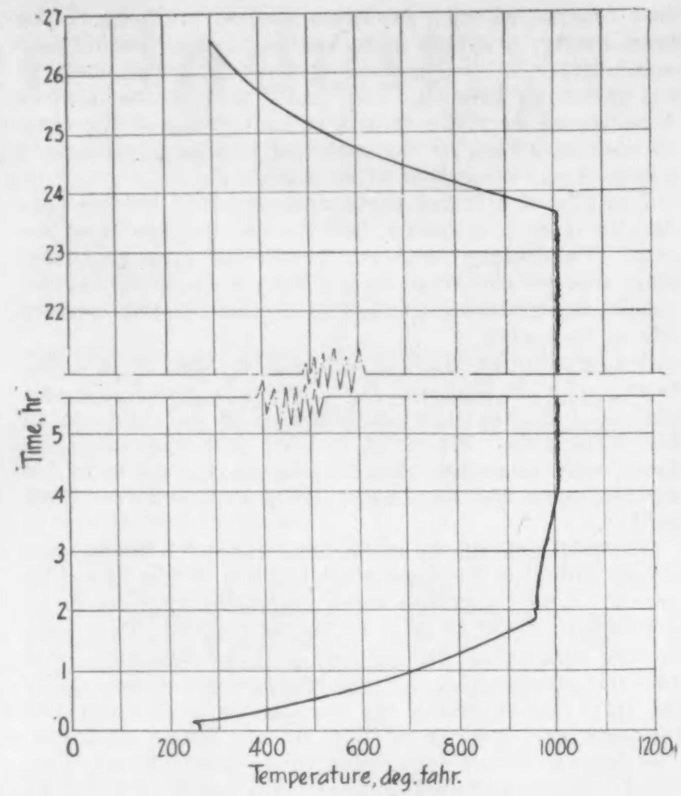


FIG. 7—CONTROL CURVE FOR NITRIDING FURNACE AT BEGINNING AND END OF 24-HR. CYCLE

The effect of time upon the case when temperature and flow are kept constant is shown in Figs. 3 and 4. From these it is evident that the total depth of the case for a given temperature and flow is a function of the time. However, the relation of time to depth is not a straight-line function. The rate of penetration gradually decreases after 24 hr. The time of the cycle must be determined for each job; cycles ranging from 24 to 72 hr. are in common use, but nitriding for more than 72 hr. is not considered economical.

One important fact is that a thin case will be much more successful if it is suitably backed up by a tough core than if the core is soft.

Ammonia Flow Influences Hardness

The rate at which fresh ammonia is introduced into the furnace materially influences the hardness of the case. The degree of dissociation obtained in the nitriding reaction varies with the rate of flow, the temperature of the work and the area of heated surface in contact with the gas. Hardness is affected more by the rate of flow at high temperatures than at low, as shown in Fig. 5. However, there seems to be a certain rate for any given temperature which results in maximum hardness and depth of case for that temperature.

Even distribution of available ammonia through the load is as important as uniform temperature. The work nearest to the incoming supply of ammonia will absorb more nitrogen than the work further away unless there is forced circulation of the gas. The concentration of the various constituents of the stream of gas changes as the nitriding reaction proceeds, and the gas soon becomes depleted of the essential ammonia which is the source of the nascent nitrogen. Sluggish circulation of

the active gas causes great variation in the amount of nitrogen observed in different parts of the load, while forced circulation minimizes this variation. We have found that reversing the direction both of the flow of ammonia into the convection furnace and the fan produces uniform depth of case and hardness. A reversing valve, which operates simultaneously with a motor switch, is so synchronized that ammonia gas enters the furnace at the bottom when the fan is blowing upward and passes directly over the work. When the fan is drawing downward, the fresh ammonia enters the furnace at the top.

Many users of the process are guided in their nitriding operation by measuring the dissociation of the exhaust gases. This dissociation value, as ordinarily measured, is an indication of the reaction but does not in itself mean much unless it is considered as a function of flow and temperatures.

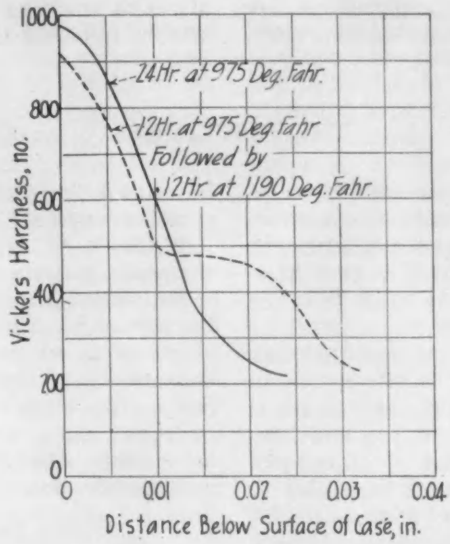


FIG. 8—RESULTS OF DUPLEX TREATMENT

The Smooth Curve Is from Uniform Treatment for 24 Hr. at 975 Deg. Fahr. The Curve Having a Hump Is from Treatment for 12 Hr. at 975 Deg. Followed by 12 Hr. at 1190 Deg.

Apparatus Selected for Uniformity of Results

The automatically controlled convection type of furnace was selected, because of the uniformity of temperature obtained in drawing furnaces embodying this principle, to meet the demand for apparatus and control methods which would unfailingly reproduce results. It has been established that radiation as a means of heating should be eliminated as much as possible for low-temperature heating; reversed convection has been proved to be a much more satisfactory method of heating for such temperatures. The Homo nitriding furnace, shown in section in Fig. 6, consists of a closed retort having gas-tight welded seams. The fan shaft is sealed by an exterior grease and asbestos-filled packing gland which can be packed without serious difficulty. Final closure is effected by a lid which fits into an oil seal outside the furnace.

Work to be nitrided is placed in the work container, which has a grid bottom, and the fan then circulates and recirculates the ammonia through the work. The direction is automatically reversed at short intervals, so that the ammonia enters the work container first from the top and then from the bottom. The ammonia enters the furnace chamber through the large pipe in the lid and is exhausted through pipe connections shown in the lower left corner of the diagram. Introducing the ammonia into a furnace of this type presents no serious problems, because the rate of circulation of the gas in the furnace is so high that the relatively small entering stream is mixed immediately and thoroughly with the rest of the gas in the furnace, so that a high degree of uniformity exists at all times as to heat and chemical conditions. An air-cooled jacket is interposed between the gas-tight chamber and the wall insulation; and a shield prevents heating the charge by radiation, aiding in the accuracy of the temperature control.

Close temperature-control of the furnace is effected by a thermocouple of low thermal capacity, mounted in the tube shown just below the fan, where it is in the path of the circulating gas. The heating and cooling portion of the control curve obtained from the recording instrument on a 24-hr. nitriding cycle is reproduced in Fig. 7. A portion of the uniform-control-temperature part of the curve, which is uniform with the portion that is shown, is omitted.

Furnace Material May Retard Reaction

Materials for the construction of nitriding furnaces have presented the most serious difficulty in their design. The ordinary heat-resisting alloys react with ammonia. Not only do they themselves break down, but they disturb the reaction that is being carried out in the furnace, because the iron nitride which is formed catalyzes the dissociation of the ammonia and the process therefore requires much greater flow of ammonia as the furnace ages to produce the same result. However, this condition has been largely overcome by the choice of suitable materials which are affected very slightly if at all by ammonia at nitriding temperatures. A suitable selection of the alloy results in a furnace structure which is neutral to the reaction. Monel metal breaks down after long exposure in a nitriding atmosphere, but the change in no way affects the efficiency of the furnace. The material seems to disintegrate through attack at the grain boundary. The crystal cement, to use the Desch explanation, constitutes a possible solid solvent which slowly but surely dissolves the grains with the assistance of the nitriding atmosphere.

Nicrome and Monel materials do not affect the reaction. The choice between the two metals is an economic problem. The Monel metal disintegrates slightly more with age.

The effect of various retort materials upon the surface hardness obtained in the product is shown by the average flow of ammonia required by furnaces having the different linings to secure comparable results after the furnaces have been in use nearly 1500 hr. A flow of 26 liters per hr. in a Monel-metal-lined furnace gave a pipette-dissociation reading of 34 per cent. Furnaces lined with other materials, similarly charged and receiving the same flow, showed pipette-dissociation readings of 23, 30 and 57 per cent.

The present tendency is to use inert liners for containers. A brick-lined Homo nitriding furnace has resulted from three years' development work on the subject of materials for nitriding containers. A furnace of this type has been in operation for more than 2300 hr. without showing any change in the hardness and depth of case of the work produced during the entire time.

Duplex Nitriding Treatment

What has been said in the foregoing refers only to results obtained when the nitriding operation is carried on at a constant temperature. Another process, re-

ferred to generally as a duplex treatment, involves carrying on the work first at a low temperature and finishing at a higher temperature. The results in hardness and type of case are shown in Fig. 8. The advantages to be derived from this type of treatment have not yet been demonstrated fully, but it is certain that a field exists for a case having the characteristics which this gives.

Nitrided parts are being used very satisfactorily in a number of applications, the most outstanding example being in valves and fittings for use at high pressures and temperatures. Other successful applications are for automobile water-pump shafts; machine-tool gearing; steam-turbine governors; various parts of locomotives; Diesel engines and range finders; and miscellaneous parts requiring high wear resistance at normal or high temperatures. However, the ease with which nitriding is done with suitable equipment should not suggest that its application can be universal.

Experience leads to the conclusion that, with suitable nitriding equipment and with materials free from strains prior to nitriding, distortion from heat-treatment is eliminated. Nitrided materials have a wide and important field of usefulness if proper attention is given to the type of case needed and to the strength of core required to back up this case.

THE DISCUSSION

HERMAN E. WINKLER[2]:—I should like a little more information in regard to the Duplex nitriding treatment.

J. MULLER:—This consists of a run of say 12 hr. at a low temperature and then 12 hr. at a higher temperature. If the higher temperature is used first, the case will be unsatisfactory and not hard.

QUESTION:—Is Nitralloy the only material that can be nitrided successfully?

MR. MULLER:—Nitralloy is the best known material for the purpose. Other materials, containing molybdenum or other alloying elements instead of aluminum, are under development. We have not yet been able to obtain the same hardness with these materials, but with further development these steels probably will meet all the hardness requirements that have been set up for Nitralloy.

J. L. GOLDTHWAITE[3]:—I should like to hear more about suitable and unsuitable applications of Nitralloy, specifically as to piston-pins, which might be subjected accidentally to a heat of 600 to 800 deg. fahr., and highly stressed gears, with reference to the core strength.

MR. MULLER:—We have made tests of nitrided steel after it had been exposed to a temperature of 700 deg. fahr. for a long time and cooled to room temperature. The hardness was maintained under those conditions, but we have made no hardness tests of steel while at high temperature.

Misapplication of Nitralloy is not uncommon, failure frequently being caused by subjecting a light case over an insufficiently strong core to excessively high bearing pressure. If the core is distorted under the pressure, the case will be cracked because it has not the ductility of the softer core material. This difficulty can be overcome by improving the base material to provide a Brinell hardness of 260 and producing a deeper nitrided case, say about 0.030 in. thick, without grinding. Many of the applications that have been unsatisfactory have been in steam valves. Distortion in Nitralloy that had not been heat-treated before nitriding made grinding necessary between the disc and the seat to obtain tightness, especially during the early development. If the distortion was great, the grinding would remove the surface hardness and the life of the parts would be sacrificed. The case should be used virtually as it comes from the furnace; a little lapping may be tolerated, but grinding deeper than 0.002 or 0.003 in. is liable to produce unsatisfactory results.

WILLIAM G. WALL[4]:—Does the ammonia affect the chemical analysis of the steel, or how does it react?

MR. MULLER:—The chemical analysis of the steel is the same after heat-treatment except for the addition of iron nitride compounds from the reaction occurring at the surface of the steel. When the ammonia comes in contact with the steel it is broken down into nascent hydrogen and nitrogen. If the ammonia is broken down before it reaches the steel, the gases will not be nascent and the reaction with the steel will not occur.

Heat-Treating for Core Strength

CHAIRMAN LOUIS SCHWITZER[5]:—Is not heat-treatment necessary to secure the desired core hardness for applications that are subject to heavy pressure?

MR. MULLER:—Such treatment is practicable for certain applications. However, any decarburized case must be removed after heat-treating and before nitriding, and the steel must be drawn at a temperature higher than that required for nitriding, say at 1100 deg. fahr., to prevent a secondary distortion. Nitriding steel can be obtained from the mill within any specified hardness range up to 260 Brinell number. Some shops will machine the material up to 260 or 280 Brinell, others no harder than 227.

QUESTION:—What is the difference in cost between nitriding and carburizing?

MR. MULLER:—A general answer to the question of cost is difficult. The cost of ammonia and power may amount to about 2 cents per lb. of material for a 24-hr. cycle, and the time required for the process is considerably longer than for carburizing. However, the material needs no further heat-treatment or finishing after the hardening. I am not prepared to give figures for the cost of carburizing.

MR. GOLDTHWAITE:—We have found some splendid applications for Nitralloy and have used a quantity of it. We have tried it on some other applications on which it has shown no advantage whatever. Some parts we have been able to make without distortion or other trouble and we have been unable to avoid distortion in other parts. The claim is made that Nitralloy does not distort if the part is annealed thoroughly; but it does grow, and the ends of a cylinder will grow more than the middle, and unsymmetrical parts will grow more on one side than on another. That may not be distortion, but it seems to have the same effect.

(*Concluded on p.* 246)

[2] Jun.S.A.E.—Engineer, Schwitzer-Cummins Co., Indianapolis.
[3] Allison Engineering Co., Indianapolis.
[4] M.S.A.E.—Consulting engineer, Indianapolis.
[5] M.S.A.E.—President, chief engineer, Schwitzer-Cummins Co., Indianapolis.

An Efficiency Formula for Cargo Airplanes[1]

By G. A. Rathert[2]

I HAVE for some time thought that a rational formula for figuring the efficiency of an airplane strictly as a cargo carrier would be of considerable help to designers and engineers as a basis for the improvement of existing designs or for making efficient new designs. Several items should enter into such a formula, the main items, in my opinion, being: speed, payload, horsepower, structural strength, stability, safety, visibility, initial cost and operating cost.

Of these items the first three have definite or concrete values for each airplane. Structural strength and stability, I believe, can be assumed as equal for all planes because all cargo-carrying airplanes must be licensed by the Department of Commerce. The Aeronautic Branch of this Department is functioning very satisfactorily and in its requirements for an approval type certificate is using the best available data. The reputable manufacturers and the Aeronautics Branch are working together for the best interests of the manufacturers and the public. This cooperation will tend to produce airplanes that are virtually equal in strength and stability.

Factors Omitted from Formula

Such part of the item of safety as comes from the strength, stability and general design may also be assumed as equal in all cargo airplanes, being regulated by the Department's requirements. The elements of safety that are not thus affected come from the use of multi-engine ships or the landing speed. The actual increase in safety obtained by the use of more than one engine still seems to be a much argued question, while the increase in safety due to lowered landing-speed is rather abstract, and it is questionable if this increase is not offset by the value of higher speeds in bad-weather flying. Therefore safety is not included in my merit rating, although its exclusion may cause unfavorable comment. It would be included if any reasonable assumption could be made as to its value.

Visibility is also assumed as equal in all airplanes, being purely abstract. We must assume, however, that manufacturers will construct planes with satisfactory visibility in order to sell them.

Initial cost and operating cost must enter into a rational formula, but I have at present no accurate figure for either. Available information indicates that initial cost favors the single-engine plane, as two or three smaller planes can be bought for less than the price of a multi-engine plane of equivalent load capacity. The operating cost at capacity load is about the same for two small planes as for one large plane. Most multi-engine planes carry two pilots. The flexibility of operation afforded by the use of three smaller single-engine planes probably offsets the cost of an additional pilot through a reasonable operating period. Since costs cannot be figured except for specific cases, they will be disregarded here, although they should be included in any merit formula. That part of operating cost which is governed by fuel and oil consumption is included directly in horsepower, the assumption being that engines of equal fuel and oil consumption can be used in airplanes of different types and sizes.

In view of the foregoing, a formula that includes only payload, speed and horsepower should be of great benefit in judging the merits of cargo-carrying airplanes. It can at least be used as a preliminary basis for the choice of size or type.

As speed is the basic reason for airplanes, it should be included in any rating at least in direct proportion to its magnitude. The fact that we provide greater power to obtain additional speed and that such power must be added approximately in proportion to the square of the speed indicates that use in the formula of the square of the speed might be advisable. But speed is used in our rating only in direct proportion to its magnitude. Payload should be a function of the formula obviously in direct proportion to its magnitude. Power is used in inverse proportion to its magnitude. The formula develops as follows:

$$\text{Merit Rating} = \text{Speed} \times \text{payload/horsepower}$$

Speed is expressed in miles per hour and payload in pounds. Therefore the merit rating is in pound-miles per horsepower-hour.

Comparative Efficiency of Types and Sizes

Data taken from a publication giving characteristics of a number of American airplanes are given in Tables 1 and 2. Some of the figures are known to be erroneous, but I believe that the averages are fair to all types and classes of airplane. Data on more than 200 airplanes were used in compiling the tabulations and no plane under 1200-lb. gross weight was considered.

Table 1 gives the averages of all planes of each type in each group, and Table 2 gives figures for the best plane of each type in each group. The figures are sufficiently accurate to show some interesting comparisons. The airplanes in Group 1 cannot be classed as cargo carriers, since most of them are training or sport planes, but I have included this group because light planes may possibly be included later as carriers in the form of fast messenger or tender planes for large airline operators or as private planes used for transporting one or two individuals with their baggage or equipment.

I desire to call attention to a few very interesting points in this tabulation. First, the highest development has occurred in planes from 2500 to 5000-lb. gross weight. This probably is due to the recent increase in four to seven-place cabin planes. Second, the ratings of

[1] From a paper presented before the Northwest Section.

[2] Chief engineer, Breese Aircraft Corp., Portland, Ore.

the planes in Groups 3 and 4 are below the ratings of Groups 1 and 2. This may be due to the greater number of small planes designed and built, but my opinion is that the greater engineering and construction facilities which the larger companies can afford, if they can afford to build the larger planes, should favor more efficient construction of the larger planes. Third, the general advantage in merit seems to lie with the monoplanes, but this advantage may be due to the fact that more attention and effort have been directed to this type.

Merit Rating Can Be Raised

The best biplane in Group 4 of modern machines is not the equal in merit, according to the formula I have used, of the best biplane in 1918. The modern plane is faster but the greater payload per horsepower of the best in 1918 more than offsets this increased speed. The merit of the average biplane in Groups 1 and 2 of modern planes is just slightly better than that of the best planes in the same groups in 1918. The individual best of modern airplanes in each of these groups shows an improvement of approximately 100 per cent. Figures are available on only one of the 1918 externally braced monoplanes. This one plane is in Group 1. The average modern airplane is 50 per cent better, and the best modern airplane in the same group is 130 per cent better.

In general, the data show that a merit rating of between 600 and 700 lb.-miles per hp-hr. is obtainable. I believe that, using existing designs as a basis and making a more balanced structure, a rating of 800 can be obtained. A more balanced structure can be obtained by adhering more closely to a predetermined margin of safety.

I know that designers as a rule show an inclination to give more consideration and care to one or more particular parts of a structure and accept what we call standard practice for the rest of the structure. If any designer has a preference for a particular type of airplane and believes it to be the most efficient, he must produce a design that shows a higher efficiency than other designs before he can convince the public that he is right.

If this paper assists toward the establishment among designers, fliers and operators of a rational basis for rating airplane performance I shall feel well repaid for its preparation.

THE DISCUSSION

CHAIRMAN WALTER R. JONES[8]:—The first criticism I would have of this method is that it is based on a characteristic rarely used; that is, the high speed of the airplane. The figure of merit should indicate the relation of the cruising speed and the power consumed at that speed to the payload. While this modification, with the present-day machines, may not make a relatively

(*Concluded on p.* 252)

[8] M.S.A.E.—Assistant professor of aeronautic engineering, Oregon State College, Corvallis, Ore.

TABLE 1—AVERAGE DATA OF LOAD-CARRYING ABILITY OF MORE THAN 200 AIRPLANES BY GROUPS AND TYPES

Group	Type	Payload, Lb.	Speed, M.P.H.	Horsepower	Pounds per Horsepower, Gross	Payload, Gross, Per Cent	Payload per Horsepower, Lb.	Lb.-Miles per Hp-Hr.
1—1,200 to 2,500-Lb. Gross Weight	Biplane	322	110.1	110	18.2	0.161	2.93	322.6
	Externally Braced Monoplane	329	113.7	100	18.1	0.182	3.29	374.1
	Internally Braced Monoplane	283	107.7	85	18.8	0.177	3.33	358.6
2—2,500 to 5,000-Lb. Gross Weight	Biplane	497	133.7	259	12.1	0.158	1.92	256.7
	Externally Braced Monoplane	764	132.8	241	15.0	0.211	3.17	421.0
	Internally Braced Monoplane	993	144.2	330	11.9	0.254	3.01	434.0
	Sesquiplane	827	143.3	273	13.3	0.228	3.03	434.2
3—5,000 to 10,000-Lb. Gross Weight	Biplane	1,257	140.4	505	11.5	0.216	2.49	349.6
	Externally Braced Monoplane	1,271	137.9	503	11.8	0.214	2.53	348.9
	Internally Braced Monoplane	1,038	138.2	469	11.8	0.187	2.21	305.4
	Sesquiplane	1,220	140.0	525	12.0	0.194	2.32	324.8
4—Over 10,000-Lb. Gross Weight	Biplane	3,157	130.0	1,392	11.6	0.196	2.27	295.1
	Externally Braced Monoplane	3,820	151.0	1,575	9.5	0.255	2.43	366.9
	Internally Braced Monoplane	2,908	136.0	1,180	11.9	0.208	2.46	334.6

TABLE 2—DATA OF LOAD-CARRYING ABILITY OF BEST SINGLE AIRPLANE OF EACH TYPE IN EACH GROUP

Group	Type	Payload, Lb.	Speed, M.P.H.	Horsepower	Pounds per Horsepower, Gross	Payload, Gross, Per Cent	Payload per Horsepower Lb.	Lb.-Miles per Hp-Hr.
1—1,200 to 2,500-Lb. Gross Weight	Biplane	400	120	90	22.8	0.195	4.44	532.8
	Externally Braced Monoplane	450	115	90	19.8	0.252	5.00	575.0
	Internally Braced Monoplane	340	105	65	21.1	0.248	5.23	549.0
2—2,500 to 5,000-Lb. Gross Weight	Biplane	795	135	180	19.8	0.223	4.42	596.7
	Externally Braced Monoplane	1,350	150	300	13.3	0.338	4.50	675.0
	Internally Braced Monoplane	1,275	155	300	13.4	0.316	4.25	658.8
	Sesquiplane	1,040	145	300	15.0	0.231	3.47	503.2
3—5,000 to 10,000-Lb. Gross Weight	Biplane	1,600	142	525	11.1	0.274	3.05	433.1
	Externally Braced Monoplane	1,307	148	450	12.0	0.244	2.90	429.2
	Internally Braced Monoplane	1,300	135	450	12.2	0.236	2.89	390.2
	Sesquiplane	1,220	140	525	12.0	0.194	2,32	324.8
4—Airplanes over 10,000-Lb. Gross Weight	Biplane	3,600	139	1,250	13.9	0.207	2.88	400.3
	Externally Braced Monoplane	3,820	151	1,575	9.5	0.255	2.43	366.9
	Internally Braced Monoplane	3,775	133	1,350	10.0	0.280	2.80	372.4

Further Experimental Work with the New Wabblemeter

Semi-Annual Meeting Paper

By F. A. Moss[1]

OUR last report to the Society described the new automatic recording wabblemeter for measuring bodily steadiness or unsteadiness. We have already pointed out its advantages in its method of recording, its property of integrating all movements made when a person stands on the platform, its convenience of use because of compactness and the method of operation and its constancy of operation under influences of temperature and weather changes.

We have been using, since May 1 of this year, the second of these instruments constructed. This is exactly like the first one, with which we had made a preliminary trial at the time of the Annual Meeting in January, 1931, except that the recording device has been set so as to make it three and a half to four times as sensitive as the first machine. This holds an advantage in that the units of measurement of unsteadiness are smaller and the possibilities of differentiation among records are consequently better. Normal records on the first instrument ran as low as three recorded wabbles. Normal records on the more sensitive instrument rarely occur lower than 10.

Our work with this new machine has included an investigation of an important variable that influences test records on the machine. This is the diurnal variation in records for the same subjects when they were at rest, and it has included the further study in application of the instrument in road tests. We shall first briefly summarize our study of diurnal variation.

Diurnal Variations in Steadiness Tests

The point has been raised in some of the previous discussions as to what variations occur in steadiness records throughout the day, with no riding or extraordinary exercise of any kind. The suggestion has been made that the constant increase in the wabblemeter record as the result of a long ride might be due to the increase in unsteadiness which comes as a routine through the day and might have no relation whatever to the result of the automobile ride. To test this factor, we arranged for five subjects to sit in our laboratory and read or talk but take no exercise from 8 a. m. until 6 p. m. The only exercise they had was in walking a short distance to lunch at 12.30 p. m.

A fairly general opinion prevails that people are much steadier in the morning than in the middle of the afternoon. That such is far from the case probably will be surprising to many. Actually, the most unsteady records obtained are the early-morning records. The 8 a. m. records were, on an average, about 60 per cent higher than the records at 2 p. m., after which time the tendency is for the records to rise slightly; but all of the afternoon records are lower than the lowest morning record. Before one road test, we took records on a group of subjects at 5 a. m. and found them to be the shakiest we had ever had on a "normal" reading. When people are pulled out of bed considerably before their normal time of rising, evidently some time is required for them to reach their lowest level of steadiness. Increasing steadiness, with the best record around 2 p. m., probably is similar to the warming-up condition that seems to be necessary for a baseball pitcher. Fig. 1 shows the diurnal variations for the group of five subjects. That there is fairly good consistency in the time at which the various subjects make their high and low scores is noteworthy. All tended to increase in steadiness until about 2 p. m.

The fact that normally, without an automobile ride, the individuals tend to increase in steadiness, and therefore the scores on the wabblemeter tend to go down until 2 p. m., accentuates the value of the increase that occurs throughout the day with the automobile road trips. In view of this study road tests should be taken, with accurate records of the time of making the tests and the increase in unsteadiness should be expressed as a percentage increase over normal for the hour of the

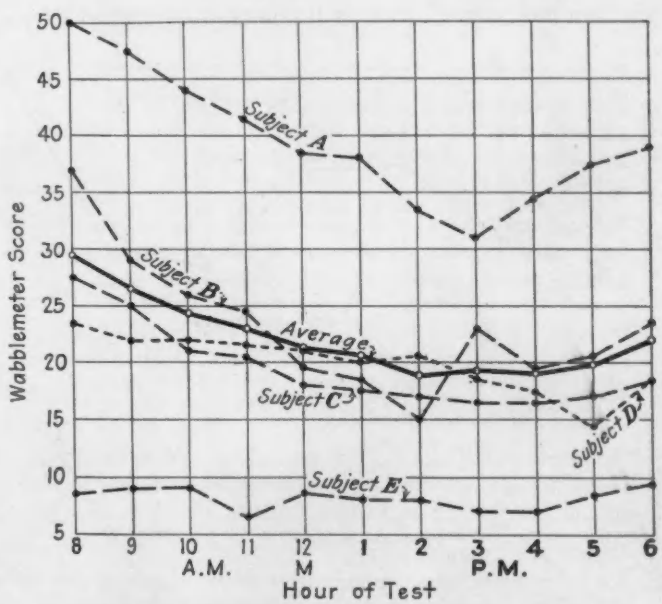


FIG. 1—WABBLEMETER RECORDS TAKEN AT 1-HR. INTERVALS ON FIVE SUBJECTS AT REST

The Heavy Curve Indicates the Average of the Five Subjects. Note the Consistency of the Times at Which the Subjects Made Their High and Low Scores and That Steadiness Increased until 2 P.M. and Then Decreased

[1] Head of department of psychology, George Washington University, City of Washington.

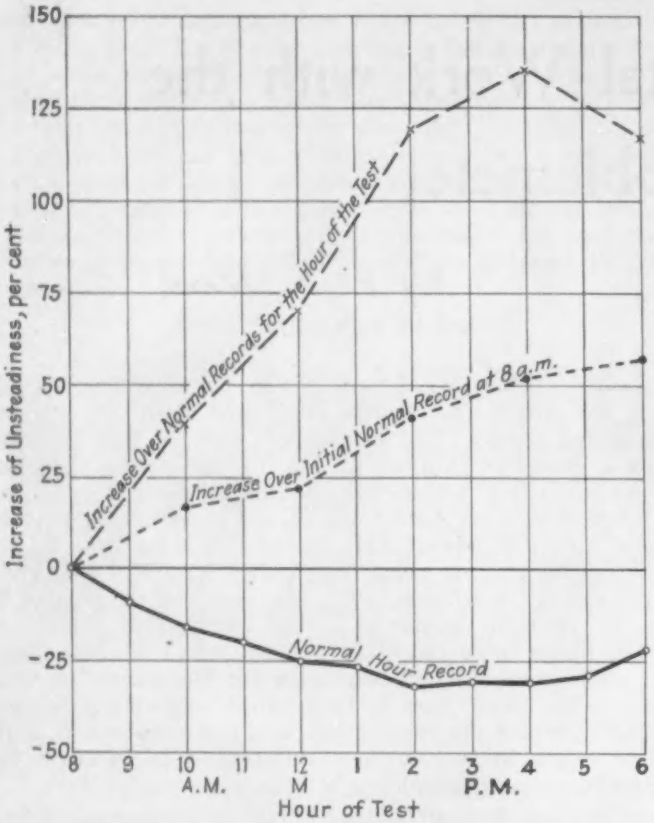


FIG. 2—INCREASE IN UNSTEADINESS ON A 300-MILE RIDE, IN PERCENTAGE

Increase over the Average Normal Record, Fig 1, for the Successive Hours Is Shown in the Upper Curve and Is Much Greater than the Increase over the Normal Record at 8 A. M., Shown in the Broken-Line Curve.

test, rather than increase over an initial normal before the trip. Fig. 2 makes possible a comparison between the two methods of judging increase in unsteadiness.

Results of Road Tests

A considerable number of road tests were made with the new instrument during six weeks in May and June, 1931. These were made in all instances with the same car and the same group of "calibrated" subjects. We have limited the experimental set-up of machine and subjects so that our initial records shall be as free as possible from the influence of variables of which, at the present stage, we could not take accurate account. Such variables include two general types, one group dependent on individual differences in subjects and another dependent on variations in external conditions such as weather conditions and time of day. Both groups are being studied in the laboratory, and, when sufficient data regarding them have been collected, the information will be applied in interpreting road-test records under a variety of conditions and with a variety of subjects.

Typical road-tests made with the new machine are now presented. These tests were made on long-distance drives over the types of highways ordinarily encountered in long-distance travel in the Middle Atlantic part of the Country. On all the trips the wabblemeter was taken in the car and tests of the subjects were taken at the end of every 100 miles driven. Average records of the six subjects have been used in summarizing. These show primarily the influence of distance driven on steadiness, although certain other factors are pointed out from the data.

Fig. 3 shows average records for a 500-mile trip made with continuous driving with the exception of the 2-hr. interval indicated on the chart. Worthy of attention in this test is the rapid rise in the records taken at *G*. These records followed a stretch driven during rain over a muddy section of road and partly after dark. The previous part of the drive was made over good roads with no rain. The drop at the rest period also shows the necessity of making road tests with a continuous trip if progressive distance-records are to be indicated.

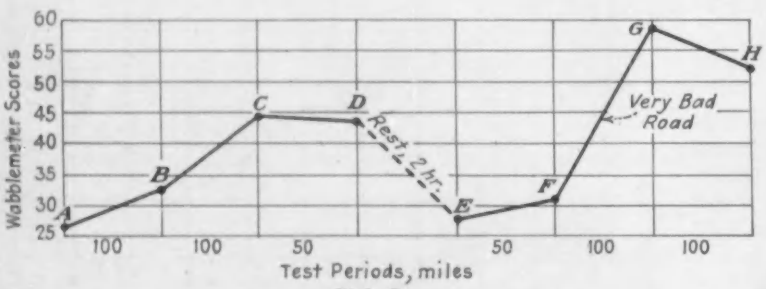


FIG. 3

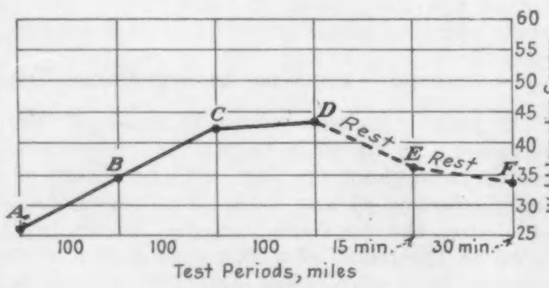


FIG. 4

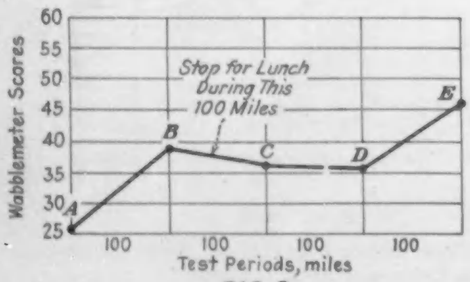


FIG. 5

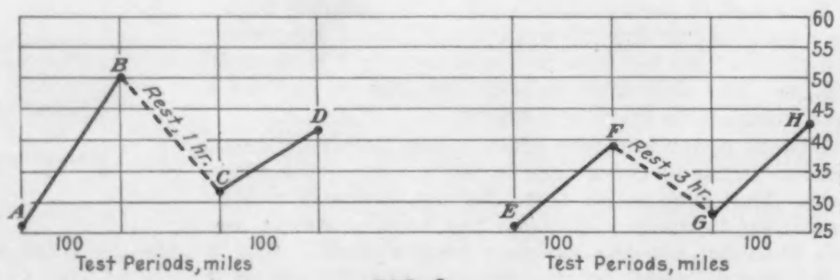


FIG. 6

AVERAGE RECORDS OF STEADINESS, AS TAKEN ON THE WABBLEMETER, FOR FOUR TRIPS OF DIFFERENT LENGTH

Fig. 3—Records for a 500-Mile Trip

Fig. 4—Records for a 300-Mile Trip

Fig. 5—Records for a 400-Mile Trip

Fig. 6—Records for the Same 200-Mile Trip Morning and Afternoon

Fig. 4 shows records for a 300-mile trip made entirely during daylight over good roads. Following this trip, tests were made after a 15-min. quiet rest, then after a 30-min. rest. We intend to follow up this line of study to determine the amount of rest necessary to restore normal steadiness after driving, as knowing how long a time is required to recover from fatigue may be just as important as knowing the amount of fatigue produced. This also indicates the necessity for making tests immediately following the trip.

Results for a 400-mile road test over fairly good roads, all except the last part of the test being made in daylight, are recorded in Fig. 5. Poorer road conditions encountered from *A* to *B* than in other parts of the trip; and heavy traffic conditions after dark, from *D* to *E*, may account for the sudden rises noted in the curve.

Records for two trips of 200 miles, driven over the same road but under somewhat different conditions, are given in Fig. 6. The first trip was made in the morning with the weather so windy as to noticeably affect driving ease. The second test was made in the afternoon with normal weather-conditions. The larger portion, of *G* to *H*, of this trip was made after dark. Rest intervals, as indicated, occurred in both these trips.

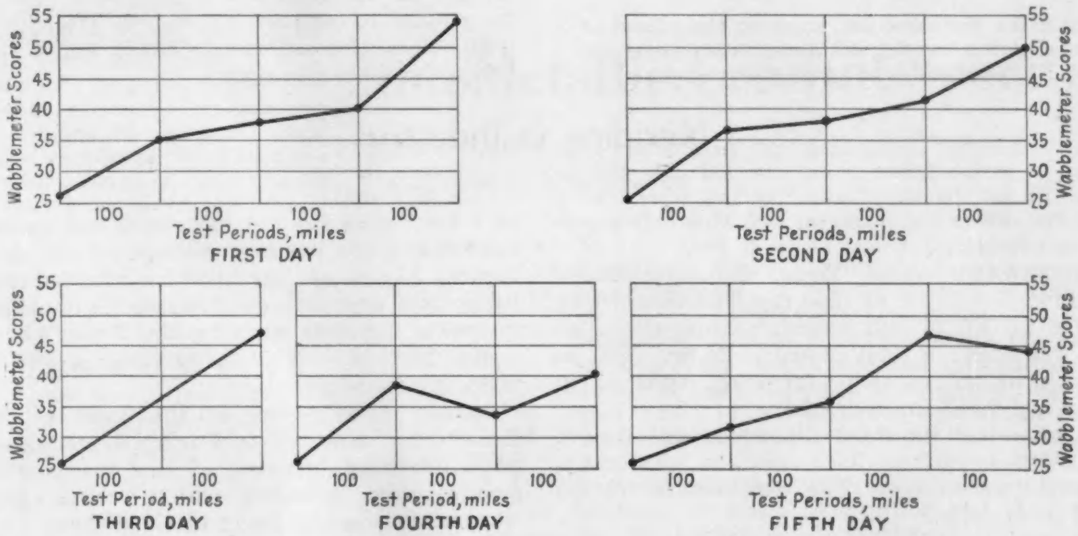


FIG. 7—WABBLEMETER RECORDS TAKEN AT 100-MILE INTERVALS ON FIVE SUCCESSIVE DAYS OF A 2000-MILE TRIP

Fig. 7 shows in terms of the new wabblemeter the 2000-mile trip mentioned in our last report[3].

Study of individual records on these tests have shown the following, which may be worthy of attention:

(1) Greater percentage increase in unsteadiness is shown by the driver than by passengers on a road test. The average percentage-increase the first 100 miles for drivers is 23 per cent as compared with 12 per cent for passengers.

(2) Average increase in unsteadiness is somewhat greater for passengers on the front seat than for those on the back seat, although results are not very constant in this respect. The greater attention to driving conditions when on the front seat probably accounts for this.

Technique of Taking Wabblemeter Records

In this test, as in any other test in which a large number of variables are involved, particular care must be taken that the tests be made under absolutely standard conditions. From the experience we have had with the machine, the following points seem to be of considerable importance in securing reliable records:

(1) *Method of Timing.*—All records should be timed with a stop-watch which is started as the levers are released and stopped as the levers are closed. In that way the timing can be done very accurately.

(2) *Absence of Distraction.*—During the test no conversation should be permitted either with the subject or with others close to the subject. People should not be moving about in the field of vision of the subject who is being tested. Having the subject face a wall while being tested is better.

(3) *Posture on the Instrument.*—In a preliminary series of experiments the subject should determine the most advantageous posture for making a good record. In general, we have found that a subject can secure his best record by focusing his eyes on a fixed object on a level with his face. Some make their best records with the arms folded over the breast, some with the arms hanging by the side, some with the arms outspread and a few with the hands clasped behind them. On all records that are to be considered, the individual should adopt the same posture.

(4) *Time of Test after Leaving Car.*—No person should be permitted to leave the test car until time for his test; that is, subjects should step on the machine immediately after getting out of the car.

(5) *Desirability of Having More Than One Test Record Each Time on Each Subject.*—We find that if we take one test record of 1 min. and then, as soon as this record is completed, take another of 1 min., the average of these two gives a much more satisfactory indication of the subject's steadiness than if only one record is taken. For that reason we recommend that two records always be taken of every subject at every test period.

(6) *Necessity of Having the Same Subjects for Comparative Records.*—To get the most usable records, the same subjects should be used through-

[3] See S.A.E. JOURNAL, May, 1931, p. 581.

out the series of tests. If, for example, one make of shock-absorber is to be compared with another, the same test subjects should start at the same time of day, driving continuously at the same rate of speed over the same roads, and should be tested at the same places, observing the technique outlined above.

(7) *Test Subjects Should Be Kept in Standard Physical Condition.*—Subjects should, as far as possible, be kept normal in sleep, drink, food and activities while being used as test subjects. This is so that the variations in records due to varying physiological conditions dependent on these factors shall be reduced to the minimum.

Plans for Future Study

We feel now that, after our tremendous amount of preliminary experimental skirmishing, we are in a position to secure data that will be of use to the automotive engineer. Plans for our summer experiments call for the following tests on automobiles:

(1) Tests using the same car, showing the effects of
  (*a*) Driving varying distances in the same car
  (*b*) Different rates of speed over the same trip
  (*c*) Driving the same distance at the same rate of speed over good roads versus bad roads
  (*d*) Fair weather versus foul weather over the same roads at same rate of speed
  (*e*) Shock-absorbers connected versus shock-absorbers disconnected
  (*f*) Springs tied down versus springs in action
  (*g*) Overstuffed cushions versus relatively firm cushions
  (*h*) Overinflated versus normal or underinflated tires

(2) The comparison of cars of the same make but of different models

(3) Comparison of different makes of car as to riding-qualities.

Tests on Airplanes.—Arrangements are being made for a series of tests on one of the main airlines, which will involve a series of records on about 3000 miles of flying. As the records will be between two large cities, we propose to compare the records after airplane riding with those after automobile riding and train riding between the same two points.

Nitriding in Industry

(*Concluded from page* 240)

MR. MULLER:—Was the material in a strain-free condition before nitriding?

MR. GOLDTHWAITE:—One large, irregular-shaped piece was drawn for 12 hr. at 1250 deg. and then drawn further for 6 hr. after each machining operation; altogether, it was drawn a total of nearly 24 hr. Yet, on nitriding, it went out of shape, growing 0.008 in. in one direction and 0.012 in. in another.

MR. MULLER:—Did its short dimension grow more than its long dimension?

MR. GOLDTHWAITE:—Yes. The exact shape of the part is hard to describe.

More Data Needed on Growth

MR. MULLER:—The problem of distortion is perplexing. Out of about 40 bushings, 30 will show growth, and 10 may show no change or a slight shrinking. We cannot tell what causes the growth and distortion; but we do know that if internal strains, such as may be developed during rolling and forging operations, are removed by annealing prior to nitriding, we do not experience much distortion. We have formulas that indicate the growth to be expected from shafts, but the results have not always agreed with the formulas. As we have not sufficient information about the growth or distortion that sometimes occurs, we should all accumulate further data which may be compiled to serve as a basis for general conclusions.

CHAIRMAN SCHWITZER:—I believe that no difficulty need be encountered from distortion in uniform round parts like shafts. These should be nitrided while hanging vertically in a basket with alternating direction of ammonia flow at a low temperature of 900 deg. fahr. We have made many pump shafts and were disturbed somewhat by discoloration at first. This did no harm, but the blue and yellow colors looked strange. The growth was so small, probably no more than 0.0005 in., that the limits for the part were not exceeded. I believe that many parts of engines will be nitrided in the future; I know one car in which nitrided camshafts are being used now with good success. Is not this being done in special furnaces made by Mr. Muller's company?

MR. MULLER:—It is being done in one of our first nitriding furnaces.

JORDAN KORP[6]:—One of the finest nitriding rooms that I ever saw was in Paris; it contained about 20 large nitriding furnaces. I saw many different automobile parts, including clutch gears, camshafts and transmission gears, being nitrided there.

CHAIRMAN SCHWITZER:—I understand that continuous nitriding furnaces have been developed which make a saving in time. Can Mr. Muller tell us something about them?

MR. MULLER:—Such furnaces are being developed by other companies[7]. I understand that nitriding begins at 800 deg. fahr. and is continued until the temperature reaches 1050 deg., at which temperature it remains for approximately 8 to 12 hr. It is said that the length of the cycle has been reduced to 16 hr., and this is a decided advantage if a satisfactory case is secured. Another furnace contains a retort similar to that used in a carburizing furnace. The fan, which is unidirectional, is at the top, and the ammonia is introduced at the top of the furnace.

J. W. Morton has described[8] a very elaborate arrangement for nitriding which includes a bell-type furnace that is removable. The heat is retained in the furnace as the furnace is moved over to the second load while the first load is cooling, and vice versa.

There is no reason why different types of furnace should not produce satisfactory nitrided cases if they are made of suitable material, maintain uniform temperature and uniform distribution of the gas throughout the charge and are operated for sufficient time. We know that the type of furnace which we make has certain advantages and produces work of very high quality.

[6] Metallurgical engineer, Leeds & Northrup Co., Philadelphia.

[7] See *Metal Progress*, October, 1930, p. 93.

[8] See *Transactions of the American Society for Steel Treating*, Vol. 18, 1930, p. 502.

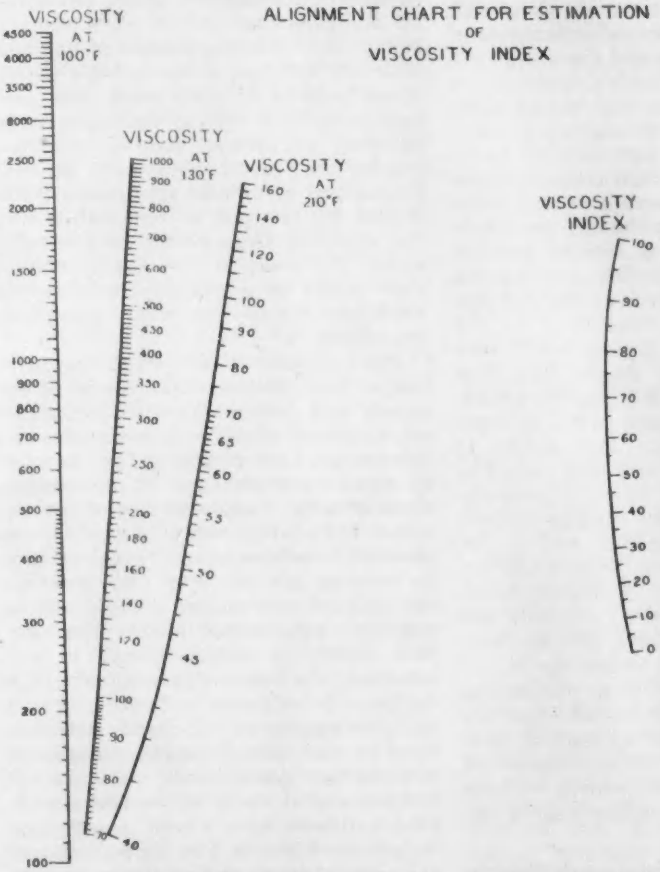
Standardization Progress

Viscosity-Index Chart

A Ready Means for Obtaining Temperature-Viscosity Data on Lubricants

THROUGH the courtesy of F. P. Gilligan of the Henry Souther Engineering Co., who is Chairman of the S.A.E. Iron and Steel Division, copies of a viscosity-index chart, shown in the accompanying illustration, have been supplied to the Lubricants Division of the Standards Committee which is interested in the development of a standard chart. The Division will study the matter further when a report is available from a committee of the American Society for Testing Materials, that is now formulating a standard chart.

The accompanying chart can be used for the rapid evaluation of temperature-viscosity data of petroleum lubricants. Dean and Davis found that the viscosity relationships of oils could be expressed as a function of the Saybolt



universal viscosities at 100 and 210 deg. fahr., by the general equation

$$y = ax^2 + bx = c$$

where

x = viscosity at 210 deg. fahr.
y = viscosity at 100 deg. fahr.

[1] See *Industrial and Engineering Chemistry*, December, 1930, p. 1326.

Although the viscosity index was developed by the use of viscosities at 100 and 210 deg., other temperatures can be used and the S.A.E. viscosities at 130 deg. are included in the chart. A straight line is drawn through points representing the values of the oil viscosities at two of the temperatures given and the intersection of this line with the viscosity-index scale will give directly the value for viscosity index of the oil. The use of the viscosity-index constant in determining the structure of an oil is described in a recent paper by Davis and MacAllister.

Copies of the chart can be obtained from the Henry Souther Engineering Co., Hartford, Conn.

Non-Metallic Conduit Specification

THE original S.A.E. Specification for Non-Metallic Conduit was adopted by the Society in 1922 and revised early in 1929. Since then the Electrical Equipment Division of the Society's Standards Committee has felt that this specification should be modernized and accordingly it was referred to a Subdivision of which L. O. Parker is chairman. A preliminary report was circulated and the following proposal, based on the comments received, is published herewith with the request that comments or constructive criticism be sent to Mr. Parker in care of the Delco-Remy Corp., Anderson, Ind., for consideration by the Electrical Equipment Division at its meeting that will probably be scheduled early this fall. The specification is intended to cover material purchased for automotive use and not for general electrical purposes.

Non-Metallic Conduit or Loom

General Information.—Non-metallic flexible conduit or loom is recommended for use as an insulated covering giving mechanical protection over insulated wire, metal tubing or other parts requiring a water, oil and acid-proof covering resistant to fire or abrasion. It is also recommended for use as a covering for copper or other metal tubing to prevent crystallization and to eliminate rattles.

Construction.—The loom shall be of single-wall construction; the material used to be strictly non-metallic and of sufficient mechanical strength so that when formed or woven into a tubing it shall pass the tests for the size specified. Finished loom shall be free from obstruction and shall permit easy introduction of the maximum size wire or other part for which it is normally suited. Loom in any length shall slip freely over a polished mandrel 12 in. long and equal in diameter to the minimum inside-diameter specified. The dimensions and weight of standard sizes are listed in the table printed on p. 253. Alternate dimensions and weights for the three sizes indicated in the table by an asterisk are for loom that can be used with standard ferrules.

Saturation.—(*a*) For a fire-resistant loom the inside and outside shall be thoroughly impregnated with an asphaltic compound or an equivalent water, acid, and fire-resisting compound. (*b*) For a general-purpose loom the inside and outside shall be thoroughly impregnated with an asphaltic compound or an equivalent water and acid-resisting compound. (*c*) For an oil-proof loom not affected by gasoline or baking varnish the inside and outside shall be thoroughly impregnated with a gum saturator or its equivalent. The saturator when dry shall be free from tackiness and gummy deposits. This impregnation is introduced to prevent absorption of moisture, oil or gasoline, to bind the material together to give

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Transportation Engineering

Urban Motorcoach Utilization

Electric-Railway Industry Promulgates Motorcoach Usage and Furthers Its Development

THE localized condition under which a motorcoach is to be operated is perhaps one of the most important factors in determining the most suitable type, according to Del. A. Smith, General Manager for the Department of Street Railways, Detroit, who presented a paper on the Utilization of Motorcoaches at the 1931 Semi-Annual Meeting. His discussion was confined to the application of the motorcoach to urban transportation.

Mr. Smith believes that the motorcoach has, and will continue to have, a very definite place in the scheme of city transportation. Excepting a few main trunk-lines in some of the larger cities, it has proved its greatest usefulness to the street-railway industry in making it possible to provide transportation in the territories between and beyond the existing street-car lines where service has become a paramount necessity but cannot be proved from a trolley-car viewpoint because of the high cost of right-of-ways, overhead and feeder construction, without the acceptance of a most definite operating loss. The motorcoach being a flexible unit, can be routed into districts that are devoid of adequate transportation, and thus new territories can be served very easily by extending or changing the routes.

The electric-railway industry tried the 29, 33, 37 and 40-passenger single-deck and some 60-passenger double-deck for a period of five years before the economy of standardization in motorcoach size became vitally apparent. The company with which Mr. Smith is associated is reasonably certain that most operators and manufacturers now recognize the desirability of standardization and are of the opinion that the 21 to 23 and the 40 to 43-passenger single-deck motorcoach are the sizes best suited for city transportation. The small 21 to 23-passenger vehicle has a definite usage in giving service in small cities and to outlying districts or sparsely settled territories in the larger cities where the quantity of service is not so essential but maximum frequency of service is necessary at the minimum cost per mile. This size of motorcoach is also very desirable in large cities that do not have other forms, or sufficient other forms, of rapid transit, and can be used very advantageously to provide a parlor-type seat-per-passenger unit in the field of selective service. On main trunk-lines and lines where the population is pyramiding or wherever extreme peak-loads are encountered, and more particularly on lines where the motorcoach has supplanted street-cars, the single-deck circulating-load street-car-type coach, seating 40 to 43 passengers, is entirely justified because it has been conclusively proved that the operating cost per mile is but 50 per cent more than for the 21-passenger coach, giving twice the seating capacity and room for three to four times as many standees as can be accommodated in the 21-passenger unit.

Trolley Coach Advantages

The vehicle originally known as the trackless trolley, but now more generally called the trolley coach or the trolley bus, incorporates into one unit many of the most desirable features of both the motorcoach and the street-car. However, in Mr. Smith's opinion, the trolley coach will not entirely supplant the motorcoach and it may never eliminate the street-car, but it should be remembered that in urban transportation it is designed to become a most formidable contender, even though the inherent route-flexibility is lacking and the cost of overhead-trolley construction and feeder equipment is an item of considerable moment.

In comparing the trolley coach with the motorcoach, Mr. Smith finds that the former is almost silent in operation; is free from engine odors and carbon-monoxide fumes; has ability to maintain high average and schedule speeds, even under winter operating-conditions; has a very simple control; has a low operating-cost and is believed to have a long vehicle-life because of the absence of engine vibration; and has extremely smooth and rapid acceleration, tests having been made of acceleration rates up to 5.6 m.p.h. per sec. The driving mechanism has been entirely eliminated from the coach body, leaving every inch of floor space available for the installation of seats and passenger movement without the necessity for unsightly engine enclosures.

Factors in Future Motorcoach Design

Mr. Smith states what he believes, and what he is reasonably sure the electric-railway industry believes, to be the pertinent factors in motorcoach design and manufacture that will render future production less intricate and the operation more satisfactory.

Body and Frame.—Reduction of the weight of vehicles used in urban transportation is particularly desirable because the necessity for a large number of stops per mile makes any excess weight a real burden. It may be desirable, and even absolutely necessary, to provide extremely strong bodies for cross-country motorcoaches, but ruggedness, beyond that which is vitally necessary to withstand the ravages of vibration, is not quite as imperative in urban transportation-service. This light-weight vehicle may possibly be attained by making use of a type of body and frame construction similar to that which has already been developed in the construction of the world's great dirigibles. Well insulated, light-weight, all-metal body-construction with chassis and body built integrally so as to be interdependent for support, seems advisable. In addition, the use of more streamlining and the elimination of all possible projections on the outside of the coach body to decrease wind resistance and provide a vehicle having a more pleasing appearance may be possible. Inside the coach body, all possible ramps and steps and also motor boxes should be reduced or eliminated, and the wheel-housings should be concealed under the seats so that every inch of floor space is available for carrying passengers and for free passenger movement.

Powerplants.—Very great improvements have already been made in engines, but even today this extremely vital part of a motorcoach remains the particular unit requiring by far the greatest maintenance expenditures. Consequently, any further improvements that can possibly be made to increase the efficiency of the engine and to prolong its life and also lengthen the general overhauling periods will be sincerely appreciated by the operator. Mr. Smith is not prepared to say whether this improvement should be a further development of the present gasoline engine or whether a substitution of the Diesel engine would be practicable, particularly in view of the accomplishments of the Diesel-powered airplane in a recent non-fueling endurance flight in Florida and also of the oil-burning racing car at the Sweepstakes held at the Indianapolis Speedway on May 30, 1931.

Referring to the loss of floor or seat space which is occupied by the engine, Mr. Smith says that one of the advantages of the trolley coach is that the driving motors are entirely segregated from the inside of the coach body. He

suggests that because the radial engine has proved so satisfactory in airplane performance, a heavy-duty water-cooled type of radial engine may be designed and successfully installed at either the front or the rear of the coach, thus reducing the space occupied by the powerplant. Since some airplane engines are built with the crankcase on top and the cylinders underneath, and as the usual coach engine is more than twice as high as it is wide, he asks whether it would not be possible to design and efficiently operate the conventional type of motorcoach engine suspended on its side underneath the coach body. Further, if this is not practical, whether it would not be possible to design and manufacture an efficient opposed engine to be installed underneath the coach floor.

Heating and Ventilation.—The new designs proposing the use of low-pressure steam, heated by the exhaust, seem to be a step in the right direction in Mr. Smith's opinion. But he advocates the elimination of carbon monoxide from the coach body without too large an expenditure for the equipment or the chance of abuse. Especially on large coaches having low-hung bodies, where the exhaust is expelled underneath or low at the rear, considerable trouble is experienced by backdraft drawing the gases up into the coach body. His company partly remedied this condition on its larger coaches by installing improvised exhaust piping to the coach roofs, which eliminates unwanted heat and annoying exhaust noises. He believes that the manufacturers should provide the necessary equipment to get the exhaust to the rear of the coach roof as quickly as possible, and that they should use every known engineering facility to keep all obnoxious engine odors and gases away from the coach patron.

Transmissions.—Much has been accomplished in providing transmission equipment on coaches to reduce the maintenance and noise to assure easier operation. The gasoline-electric drive accomplished these purposes very successfully but only at the expense of some 2000 lb. in added weight and several thousand dollars in additional cost of each vehicle so equipped. This additional weight and cost seem entirely impractical on all but the larger motorcoaches. Since automobiles are now being equipped with syncro-mesh transmission and free-wheeling, Mr. Smith asks whether it is not possible to provide similar equipment on the motorcoach to give added flexibility in operation without seriously increasing the first cost and the maintenance expense. Because of the multiplicity of the coach driver's duties, the need for easier handling is rightfully recognized as a vital matter; consequently, any improvement in the transmission or, if possible, the elimination of the transmission entirely, seems highly desirable. Therefore, he asks also whether the use of a power clutch or some form of a fluid flywheel or clutch to supersede the present flywheel, clutch and transmission and the gasoline-electric drive are feasible.

Steering Mechanism.—Much has been said and done about relieving the coach driver from the arduous task of gear-shifting, but very little about affording relief from the task of steering. It is true that the present mechanical steering-devices on the urban-type coaches used by Mr. Smith's company are very efficient, but with each increase in vehicle size the steering-wheel has been increased in diameter to increase the leverage, compelling the drivers to maintain an unnatural position while steering the coach. A simple, easily maintained power-actuated steering-device equipped with a steering-wheel similar in size to those on automobiles would reduce the driver's fatigue and would, he believes, tend to give greater coach flexibility, result in increased schedule speeds and prevent many traffic accidents.

Perhaps the future rubber-tired vehicle will be featured by the reduction of noise to the lowest possible minimum, Mr. Smith says; the use of engineering principles that we now find associated with the production of aircraft, making the coach more accessible by greater facilities for ingress and egress of passengers; proper circulation of the passenger movement; greater utilization and more economical use of street space; increased acceleration and deceleration, resulting in higher schedule speeds; and increasing the riding-comfort to a point where it approximates the facilities now afforded by the privately owned car.

Helpful Hints on Selecting Drivers

THE INTERVIEWER of applicants for drivers' positions should watch carefully for indications of physical and mental defects.

By watching how a candidate uses his feet, hands and body in walking, standing or writing, any serious crippling or nervous unsteadiness can usually be detected.

Eyes can be tested by having the man read newspaper print at arm's length, with each eye separately while holding a card over the other eye. The sight of men who wear glasses should be tested with and without them, to determine how great a handicap their loss or breakage would be and whether the glasses really improve vision. Vision should be approximately normal in both eyes, or corrected to normal, before the driver is permitted to drive. Color-blindness usually can be detected by asking the applicant to select a certain color from a large number of red, green and gray yarns or cards of various shades.

Hearing can be tested by asking the candidate to listen to the ticking of a watch; in a quiet room he should be able to hear it tick when 3 to 5 ft. distant.

Men who are very slow to react to situations which suddenly confront them, or who easily become rattled, can often be detected by observing how quickly the applicant responds when spoken to, and whether he becomes confused when instructed suddenly to do several different things in quick succession.

If a man cannot successfully follow simple instructions or fill out accurately the blanks on an ordinary application form, he may be too ineffectual mentally to become a good driver and his intelligence should be questioned. He should be able to read well so that he can understand traffic signs.

Some men, who may be otherwise desirable, are handicapped by health, financial, family or other worries, which make it impossible for them to be continually alert and attentive while driving. If such a mental state can be discovered in interviewing the applicant, he may be saved from possible accidents by being placed, temporarily at least, in some other work, by adjusting the difficulties causing his worry, or by postponing his employment as a driver until the unhappy mental state has passed.

In any case in which the examiner detects or suspects deficiencies in an applicant, he should insist on further examination by a physician.

Previous Employment Record

Questioning an applicant about his previous employment may yield the required information regarding his driving experience, dependability, mechanical knowledge of motor-vehicles, and other qualifications, but investigation of references from former employers is more reliable and helpful for this purpose.

It is especially important to learn what accidents an applicant may have had, when and where they happened, how much damage was done, what types of vehicles were involved, whether he, as driver, was arrested and if so, whether he was convicted. It is also desirable to learn what he believes were the causes of these accidents and what he would do now to prevent each one were he again to find himself in the same situations. It is better to bring out these points in conversation than to ask him to describe his accidents in writing on an application form. In such conversations the examiner can ascertain whether he is dealing with the type of man who expects everyone to get out of his way and refuses to accept any blame for an accident, or the type to whom each slight mishap is an experience from which he profits and so improves his driving ability.

In some cities, police departments or

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Production Engineering

Fabricating Stainless Steel

Advice on Welding, Drawing and Finishing Sheet Metal Given by C. C. Snyder[1]

A WIDELY-USED type of non-corroding steel alloy is known as the 18-8 or Krupp Nirosta KA-2 steel. This material has remarkable ductility after heat-treating at a temperature of approximately 2000 to 2100 deg. fahr. It is austenitic and work-hardens rapidly, but subsequent high-temperature annealing removes all cold-working strains and softens the material so that further deep drawing is possible.

Stainless steels of the 18-8 class are very readily welded by the spot, resistance, arc and acetylene methods. Welds are tough and resist corrosion well, and no heat-treatment is required except for protection against severe corrosion conditions. A low-carbon KA-2S welding rod should always be used. For arc welding, a special coating is applied to the rod, to act as a flux.

This alloy is used extensively to resist all types of corrosion and has no superior for atmospheric corrosion. The top temperature for oxidation or scaling is 1600 deg. The alloy should not be used for alternate heating and cooling because of the difference in coefficient of expansion between the metal and its protective scale, which causes the scale to free itself under those conditions and results in early failure. In the presence of sulphur gases, the 18-8 alloy should not be used at temperatures higher than 1200 deg. fahr.

Fabricating Sheet-Metal Parts

Specially developed lubricants are advised for drawing 18-8 sheets. One of the most popular of these is a mixture of lithopone and linseed oil, to which chalk and sulphur are sometimes added. Nearly all manufacturers of lubricants are now selling compounds which are quite suitable for the purpose. If annealing must be resorted to in order to finish the drawing, the lubricant should be cleaned off first, as some lubricants will dot the surface of the material. The annealing temperature should be about 2000 deg. fahr. for best ductility, and the metal must be cooled rapidly afterward.

A pickling solution containing 8 per cent of sulphuric acid and 2 per cent of hydrochloric acid has been found to be best. This should be followed by a 20-per-cent nitric-acid bath, to give a white pickled finish and maximum resistance to corrosion. The pickling temperature should be 130 to 160 deg. fahr. The acid percentages are by volume.

Finishing Stainless Steel

The surface condition of the material determines the grit which should be used at first in polishing. A manufactured abrasive having a grit of 150 to 180 is recommended ordinarily for 18-8 sheets. This should be followed with 200 emery, 240 flour, and buffing with an alumina buffing compound. A light buff with chromium-oxide stick is recommended for coloring. The direction of polishing should be changed at each wheel, if the shape of the work permits, to remove the polishing lines left by the previous wheel. A curved shape such as a lamp shell should be rotated against the wheel as it is polished. Highly developed automatic polishing-machines for polishing lamp and radiator shells are largely responsible for the high production and low cost of these parts at the Ford plant.

Pickle-finished sheet or strip is used for most deep-drawn shapes, because lubricant is never effective on bright surfaces and the sheet readily than does the dies; also, a ground sheet tends to show granulation more readily than does the pickle finish. However, if the draws are light and there is little likelihood of marking the sheet in the dies, a ground-finish material is obviously the more economical to use. In this case, the desired finish can generally be obtained by using a 200 or 220-grit wheel, followed by buffing.

[1] Metallurgist, Republic Steel Corp., Central Alloy district, Massillon, Ohio. Abstract from Indiana Section Meeting Paper.

New Bond for Grinding-Wheels

THE BINDERS that are used in the manufacture of grinding-wheels include clay, shellac, bakelite, rubber and silicate. These binders have different strengths, which allow different flexibility ratios and rim speeds. The clay-bonded wheels, having practically no flexibility and less strength per square inch than wheels bonded with organic binders, present difficulties because of the difference in the coefficient of thermal expansion between the binder and the abrasive. This has a tendency to set up unnatural stresses and strains within the mass and to cause distortion in the wheel face.

As a result of long investigation and experimentation in the field, the Norton Co. has developed a new binder which coordinates with the abrasive grains under the influence of heat or, in other words, has the same coefficient of thermal expansion. This new bond has replaced the clay-bonded wheels to a large extent in precision grinding throughout the automotive industry. No. 38 Alundum wheels, made with this new bond, are a pure white product, very attractive and unusual in appearance.—From a paper presented by Arthur W. Cox at a meeting of the Northwest Section.

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courts maintain records of drivers who have been penalized for violating motor-vehicle laws. When these records can be consulted, they are valuable in judging the ability of an applicant and in verifying his statements. In some localities similar data may be had from State motor-vehicle departments.

The amount of driving experience required should depend largely upon the facilities of an organization for training drivers after they are hired. Some of the large bus companies prefer men who have had no driving experience, for these can be trained in good habits from the start. Other companies make it a practice to train helpers as drivers so that, when new men are needed, they can be chosen from the organization. In this case the helper is an apprenticed driver and the management is able to judge his abilities.

When new drivers cannot be trained, at least a year's experience or 5000 miles of driving is desirable. It is better, however, to rely upon road tests, which will show how well the man can drive, than upon a statement of how long he has been driving.—*National Safety Council Pamphlet No. D-2.*

Personal Notes of the Members

Tilley now with American Airplane & Engine Corp.

Norman N. Tilley assumed the duties of assistant engineer of the American Airplane & Engine Corp., of Farmingdale, Long Island, N. Y., on July 1. For about two years previously he had been chief engineer of the Kinner Airplane & Motor Corp., of Glendale, Calif.

Mr. Tilley is well known for his long service in the Army Air Service, which he joined in 1918 as instructor on aviation engines at Cornell University. During the next two years he served as a flying cadet and airplane-pilot student officer. In 1921 he was professor of mechanical engineering at the New Mexico Agricultural and Mechanical College, and the following year was instructor in mechanical engineering at the University of Texas. He reentered the Air Service in June, 1922, as test engineer in the engineering division at McCook Field, Dayton, Ohio, and in that year joined the Society as a Service Member. From then to 1928 he was successively research engineer on aviation engines, associate mechanical engineer in the Materiel Division in charge of the engine specification and development unit of the Powerplant Branch of the Materiel Division at Wright Field. He left the Materiel Division with the rating of Mechanical Engineer to enter the commercial field in 1929 as chief engineer of the Kinner company.

Mr. Tilley has been a member of the Aircraft-Engine Activity Committee during 1930 and 1931, was a member of the Dayton and Southern California Sections and has presented several papers at S.A.E. meetings, one of which, entitled Small Airplane-Engines, was published in the S.A.E. JOURNAL, March, 1930, p. 346.

Aeronautic Association Officers Reelected

At the annual election of the National Aeronautic Association in the City of Washington on July 24, the officers and most of the members of the board of governors who served last year were reelected. Members of the S.A.E. who will serve for the new year include Miss Amelia Earhart, vice-president of the New York, Philadelphia & Washington Airway Corp., reelected vice-president of the Association; Porter H. Adams, reelected chairman of the executive committee; Charles F. Lienesch, aviation manager of the Union Oil Co. of California, elected governor-at-large to succeed Col. Benjamin F. Castle, president of the Great Lakes Aircraft Corp.; Orville Wright, Porter H. Adams and William P. MacCracken, Jr., reelected governors-at-large; L. S. Horner, representing the District of Columbia; Glenn L. Martin, representing Maryland; and Charles L. Lawrance, representing New York State, reelected governors.

Muffly Joins Staff of N.E.M.A.

Louis Ruthenburg, president of Copeland Products, Inc., and chairman of the Refrigeration Division of the National Electrical Manufacturers Association, announced in July that Glenn Muffly, consulting engineer of Copeland Products, had become a member of the staff of the association and will be located at the headquarters of the N.E.M.A. in New York City. His particular function is to handle matters relating to the refrigeration safety code, on the standardization of which he has long been active. He was a member of the Sectional Committee that formulated the code adopted by the American Standards Association in 1930. He is also vice-president of the American Society of Refrigerating Engineers.

Mr. Muffly, as well as Mr. Ruthenburg, is a Member of the Society, having been admitted in 1916, and has been connected with Copeland Products since October, 1925, as chief engineer and consulting engineer. He retains the latter relation.

Leslie Appointed to Business Fellowship

John C. Leslie is one of six men who were appointed to the first fellowships in an experiment to promote business leadership and make it possible for a small group of carefully selected young men to develop their natural qualities of leadership, vision and sound judgment by special professional training. The experiment is to be conducted in the department of business and engineering administration of the Massachusetts Institute of Technology, from which these men were graduated. The fellowships were awarded after a careful analysis of the records of the 3500 graduates since 1925. The sponsors of the experiment are six industrial business leaders. Mr. Leslie has been granted an indefinite leave of absence by the Pan-American Airways, by which he was employed as assistant division engineer at Miama, Fla., to enable him to undertake this year of additional study in business leadership.

Harry G. Baldwin recently accepted the position of engineer with the Norma-Hoffmann Bearings Corp., of Stamford, Conn., manufacturers of ball, roller and thrust bearings.

R. M. Bean, of Syracuse, N. Y., has bought a one-half interest in the Revere Products Corp., of Phoenix, N. Y., and has been elected secretary and treasurer and a director of the corporation, which manufactures metal stampings for automotive and other uses.

Information has been received that **Lyman H. Bellows**, formerly sales manager of the automotive maintenance division of the Arco Co., of Cleveland, now acts as manager of the Cleveland office of the Stanley Electric Tool Co., of New Britain, Conn.

Nils G. Bjorck has been appointed chief engineer of the National Motor Truck Manufacturers Association, with headquarters in Chicago. He was formerly chief engineer of the Lange Motor Truck Co., of Pittsburgh.

Having resigned his position as production manager of the General Motors Export Co. for Japan, **John H. Berry** now occupies the same post with the Vauxhall Motors, Ltd., of Luton, Bedfordshire, England.

Clare Wesley Bunch, formerly engineer and Wichita branch manager of the Pioneer Instrument Co., of Brooklyn, N. Y., is now located at Linn Creek, Mo.

Harold E. Butcher, formerly vice-president and director of sales of the Edward G. Budd Mfg. Co., of Detroit, has severed his connection with that company. His present address is Hawthorne Road, Ottawa Hills, Toledo.

Isaac Char, who was a layout draftsman in the special-equipment division of Chrysler Motors, of Detroit, is now owner and engineer of the Automotive Engineering Service Shop, of Los Angeles, which builds special bodies for commercial vehicles.

John Coapman is now connected with the Motor Wheel Corp., of Lansing, Mich. He was formerly a sales representative of the Timken-Detroit Axle Co.

Franz W. Cook has accepted the position of sales engineer with the Carter Carburetor Corp, of Detroit.

Chris J. Fields is at present employed as layout man by the Pierce-Arrow Motor Car Co., of Buffalo.

Information has been received to the effect that **Charles Bayly Franklin** has resigned his post as chief engineer of the Indian Motorcycle Co., of Springfield, Mass.

After having severed his connection with Adam Opel, A.G., of Russelsheim a. M., Germany, which concern he had

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Applicants Qualified

The following applicants have qualified for admission to the Society between July 10 and August 10, 1931. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff.) Affiliate; (S M) Service Member; (F M) Foreign Member.

BARKER, FREDERIC R. (M) engine designer, Lycoming Mfg. Co., Williamsport, Pa.; (mail) *Georgetown, Mass.*

BERGHOFF, BREDO H. (M) assistant chief engineer, Stalingrad Tractor Plant, Stalingrad, U.S.S.R.; (mail) 24 Tostrups Gate, *Oslo, Norway.*

BURN, LEWIS (F M) managing director, consulting engineer, Turn Transportation, Ltd., *Longparish, Hants, England;* (mail) Tudor Cottage.

CHENEY, MOSES EDWARD (M) chief engineer, Moto-Meter Gauge & Equipment Corp., 449 Hamilton Street, *Toledo.*

COOPER, EDWIN O. (A) chief mechanic and manager, Pacific Airmotive Corp., Oakland, Calif.; (mail) 2115 San Antonio Avenue, *Alameda, Calif.*

DEPEW, CHESTER C. (J) assistant research engineer, Aeromarine Plane & Motor Co., *Keyport, N. J.;* (mail) 6 Walnut Terrace.

FREEDMAN, ISAIAH (J) mechanic, Central Motors, *Sioux Lookout, Ont., Canada.*

GARRETT, HUGH C. (A) sales representative, Vacuum Oil Co., *Kansas City, Mo.;* (mail) 4246 Charlotte Street.

GILMER, LOUIS A. (J) mechanical engineer, International Engineering Corp., Chicago; (mail) 15535 Myrtle Avenue, *Harvey, Ill.*

HAMERLY, F. B. (M) vice-president and works manager, Independent Pneumatic Tool Co., *Aurora, Ill.*

HEMKE, PAUL E. (M) associate professor of mathematics and mechanics, Post Graduate School, U. S. Naval Academy, *Annapolis, Md.;* (mail) R.F.D. No. 3.

KELLOGG, HUDSON W. (J) manager of gasoline testing laboratory, Ethyl Gasoline Corp., 716 East Milwaukee Avenue, *Detroit.*

LEE, Y. C., GEN. (M) director, Liao Ning Trench Mortar Arsenal, *Mukden, China.*

LUDLOW, EDMUND (J) assistant to chief engineer, Noblitt-Sparks Industries, Inc., *Indianapolis;* (mail) 3546 Balsam Ave.

MACLEAN, ANDREW DYAS (A) editor and vice-president, Hugh C. MacLean Publications, Ltd., 347 West Adelaide Street, *Toronto, Ont., Canada.*

MATHEWS, HARRY O. (A) superintendent of motor equipment, Illinois Bell Telephone Co., *Chicago;* (mail) 1531 West Harrison Street.

MCADAM, FREDERICK EDWARD (A) European district manager, Firestone Tire & Rubber Export Co., Akron, Ohio; (mail) Hasenauerstrasse 12, *Vienna, Austria.*

MCMANN, WILLIAM J. R. (A) 170 East 94th Street, *New York City.*

MURPHY, H. M. (A) truck-division sales manager, Walsh Motors, Inc., 3230 Troost Avenue, *Kansas City, Mo.*

NEW JERSEY ZINC CO., INC. (Aff.) 160 Front Street, *New York City;* Representatives:—Brannin, D. P., sales, Chicago; Maxon, C. R., sales engineer.

PEARSON, HAROLD CHARLES (A) sales manager, Dewey & Almy Chemical Co. of Canada, Ltd., *Farnham, Que., Canada.*

PHALON, EDMOND H. (A) manager of service distribution, Borden's Farm Products Co. of Illinois, *Chicago;* (mail) 2101 West 69th Street.

SAVAGE, GEOFFREY HERBERT (F M) production manager, Rover Car Co., Ltd., Meteor Works, Coventry, England; (mail) Priors Field, Fieldgate Lane, *Kenilworth, Warwickshire, England.*

SAYEGUSA, SADAMU (J) assistant designer, Tokyo Gas & Electric Engineering Co., Ltd., Tokyo, Japan; (mail) 338 Senoshitamachi, Kurume-shi, *Fukuoka-ken, Japan.*

SCHNEIDER, KURT (M) designer, Fisher Body Corp. division of the General Motors Corp., *Detroit;* (mail) 5920 Cadillac Avenue.

SORIA, GUIDO, ING. (F M) central director, Fiat Co., *Turin, Italy;* (mail) Via Cosseria 9.

STODDARD, ROBERT W. (J) assistant manager of aviation division, Wyman-Gordon Co., *Worcester, Mass.;* (mail) 7 Massachusetts Avenue.

STUMP, ROBIN D. (J) clerk, engineering studies, Illinois Bell Telephone Co., *Chicago;* (mail) 4658 Milwaukee Avenue, Apartment 2E.

TAYLOR, GAVIN R. (M) chief chemist, McColl-Frontenac Oil Co., Ltd., *Montreal, Que., Canada;* (mail) 2540 Notre Dame Street, East.

TAYLOR, H. B. (M) superintendent of maintenance, American Airways, Inc., Love Field, *Dallas, Tex.*

THOMPSON, J. V. (A) vice-president and general manager, Thompson & Co., 1085 Allegheny Avenue, Oakmont, Pa.

WEBER, J. P. (J) representative, Bendix-Westinghouse Automotive Air Brake Co., Pittsburgh; (mail) 760 Hippodrome Annex, *Cleveland.*

WEGFORTH, JOHN FRED, Lieut. (S M) aviation assembly and repair officer, U. S. Navy, Naval Air Station, *Hampton Roads, Va.*

WHISTLER, JOHN M., First-Lieut., U. S. A. (A) 17th Field Artillery, *Fort Bragg, N. C.*

WORKMAN, JAMES H., First-Lieut., U. S. A. (A) Field Artillery School, Fort Sill, Okla.; (mail) 219 Waldron Street, *West Lafayette, Ind.*

An Efficiency Formula for Cargo Airplanes

(*Concluded from p. 242*)

great difference in these figures of merit in some designs, attention has been paid to the fact that the machine operates 95 per cent of the time at cruising speed.

I agree that a figure of merit is very desirable and I think Mr. Rathert is on the right track, because the Boeing Model 95 heads the list in Group 3. However, I know that in this design considerable attention was given to two points; first, to producing a machine that would fly most economically at cruising speed, not at high speed; second, we did not want a ship that would fly economically at sea level but after it has reached a certain altitude. The average altitude at which the planes fly from San Francisco to Chicago is somewhere between 5000 and 10,000 ft., and as the ship must earn money at 8000 ft., it was designed to have a certain economical speed at that altitude. Most airplanes are designed primarily for operation at sea level or thereabouts, and that certainly makes a difference in the performance.

Another thing that must be taken into account is the ability of the airplane to climb. A ship that is not sufficiently powered and that does not have enough wing area will not have sufficient climbing ability to be economical in the transcontinental flight, as for instance, for the take-off at Salt Lake City at an elevation of 4200 ft. and the immediate rapid climb necessary to clear the mountain ranges surrounding the airport.

In designing the Boeing 95, considerable attention was paid to climbing ability and a compromise was reached between speed and climb, with the result that the high speed was cut down. If the wing area is reduced by a considerable amount to obtain a higher speed, it will give a higher figure of merit but an inferior ship for that particular duty.

These points are difficult to incorporate in arriving at a figure of merit as proposed by Mr. Rathert, but, while the formula is a ready means for comparing average airplanes, all these special considerations should be included before a decision is reached as to which is really the more meritorious design.

G. A. RATHERT:—I remarked about the discrepancy between the figures of merit of the larger ships compared with the biplane design. I think that the public demands more consideration in the larger ships, particularly in the passenger carrier. Passengers in the smaller ships seem to be willing to sit in a cramped chair with insufficient headroom and aisle space and with no accommodations, but they want to be able to stand up in the large trimotor transports with greater facility than in an automobile, and they want lavatory and restaurant facilities, all of which tend to lower the over-all figure of merit.

Applicants for Membership

The applications for membership received between July 16 and Aug. 15, 1931, are listed below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

ADAMS, LEON A., principal mechanic, shop foreman, United States Bureau of Public Roads, *Vancouver, Wash.*

BERTONE, EUGENE, president, Bertone Fuel Reaction Corp., *Pikesville, Md.*

CAMPBELL, WILLIAM S., instructor of motor engineering, Vancouver Technical School, *Vancouver, B. C., Canada.*

CHRISTIE, ROBERT M., president, Christie Machine Works, *San Francisco.*

CURTIS, THOMAS H., 26 Towerhill Avenue, *Red Bank, N. J.*

DRYSDALE, GEORGE W., superintendent, commercial division, Briggs Mfg. Co., *Detroit.*

HARRIS, ELWOOD K., instructor, General Motors Institute of Technology, *Flint, Mich.*

HAWKEY, LESTER F., salesman, Edison Storage Battery Co., *Kansas City, Mo.*

HOLT, HARRY, JR., Oldham & Son, Ltd., Denton, *Manchester, England.*

JACKSON, D. H., brake service engineer, James C. Gay, *Los Angeles.*

KAHN, J. KESNER, president, Kahn Aircraft Co., 5710 Woodlawn Avenue, *Chicago.*

LOCKE, ARTHUR A., development and plant engineer, Wolverine Tube Co., *Detroit.*

MENZ, PETER G., checker, motor engineering department, Wright Aeronautical Corp., *Paterson, N. J.*

MONEY, R. S., service manager, S. T. Son's & Co., *Trichinopoly, India.*

PADDOCK, PAUL DARROW, technical publicity, Hayes, Loeb & Co., *Chicago.*

PALMER, ARTHUR E., assistant engineer, Hyatt Roller Bearing Co., *Harrison, N. J.*

PORTER, R. C., service engineer, Gatke Corp., *Chicago.*

RAWLINGS, EDWARD E., manager, eastern section, manufacturers service division, Vacuum Oil Co., *New York City.*

ROSE, HAROLD L., chief inspector, Kingston Products Corp., *Kokomo, Ind.*

TAYLOR SALES ENGINEERING CORP., *Elkhart, Ind.*

THOMPSON, ROY E., engineer, Lamb-Grays Harbor Co., *Hoquiam, Wash.*

TRUMP, HERBERT JOHN, ordnance mechanical engineer, Royal Army Ordnance Corps, Mechanical Warfare Experimental Establishment, *Pinehurst, Farnsborough, Hants, England.*

WALTERS, BERT, member of service department, Southard Motors, Ltd., *Vancouver, B. C., Canada.*

Standardization Activities

(*Concluded from p.* 247)

the required wall strength and to prevent fraying.

Finish.—(*a*) For a fire-resistant loom the outer surface shall be thoroughly covered by an asphaltic or equivalent water, acid and fire-resisting compound. (*b*) For a general-purpose loom the outer surface shall be thoroughly covered with at least two coats of black pyroxylin lacquer or its equivalent, producing a good luster and a good bond to the fabric. (*c*) For an oil-proof loom the outer surface shall be thoroughly covered with at least two coats of black pyroxylin lacquer or its equivalent, producing a good luster and a good bond to the fabric. The lacquer must be thoroughly dried before wrapping or boxing the loom for shipment. The use of heavy finishes or saturators to give artificial appearance is not permitted. The pyroxylin must be sufficiently plasticized so that it will not crack on a piece of loom kept three months at room temperature and then bent back sharply upon itself. Loom with finish of a higher luster than can be obtained with two coats of lacquer as specified above shall be considered special and should be covered by other specifications when required.

Tests.—(*a*) A 6-in. piece of loom totally immersed in water at 70 deg. fahr. for 24 hr. and then blown out with a mild air current immediately after removing the water shall not have an increase in weight of more than 35 per cent. (*b*) The wall must not collapse when the loom is bent to a radius of five times the inside diameter at 70 deg. fahr. The compound and finish must not crack open in this test. The material in the wall of the loom shall not crack or break when a 3-in. length is flattened between the jaws of a vise, in accordance with the following table. The finish shall not show excessive cracking when loom is subjected to this test.

Loom, Inside Diameter, In.	Distance Between Jaws, In.
3/8 and under	11/64
over 3/8	9/32

The polished mandrels used for checking the inside diameters shall show no sticking or discoloration up to 150 deg. fahr.

(*c*) Loom shall be capable of standing a tension test for 5 min. without breaking or opening at any point as follows:

Loom, Nominal Size, In.	Minimum Tensile Rquirement, Lb.
3/16	75
1/4	85
5/16 and 3/8	100
7/16 or larger	150

The test piece shall be 6 in. long between supports.

Additional Test for the Oil-Proof and Fire-Resistant Loom.—When a piece of loom is totally immersed in an equal mixture of cylinder oil, kerosene and gasoline at 70 deg. fahr. for 5 min. and then subjected to a temperature not exceeding 250 deg. fahr. for 1 hr., the saturating compound must not drip from the loom or the finish show any appreciable defects.

Fireproofing.—Flame-resisting qualities shall be incorporated in the saturation or finish, or both, to pass the following test: The loom shall not convey fire nor support combustion for more than 1 min. after five 15-sec. applications of a standard test-flame with intervals of 15 sec. between applications. A standard test-flame is the blue flame, about 5 in. high, produced by a ½-in. Bunsen burner fed with ordinary illuminating gas at normal pressure. The loom shall be held vertically with either the lower or the upper end thoroughly sealed to prevent the passage of air, and the flame must be applied horizontally.

Nominal Size, In.	Inside Diameter, In.		Outside Diameter, In.		Approximate Weight per 1000 Ft., Lb.
	Minimum	Maximum	Minimum	Maximum	
3/16*	0.187	0.207	0.277	0.297	10.0
3/16	0.187	0.207	0.287	0.307	14.0
1/4*	0.250	0.270	0.340	0.360	15.0
1/4	0.250	0.270	0.350	0.370	19.5
5/16	0.312	0.332	0.412	0.432	22.0
3/8*	0.375	0.395	0.475	0.495	26.0
3/8	0.375	0.395	0.505	0.525	28.0
7/16	0.437	0.457	0.567	0.587	33.0
1/2	0.500	0.520	0.630	0.650	38.0
9/16	0.562	0.582	0.722	0.742	42.0
5/8	0.625	0.645	0.785	0.805	46.0
11/16	0.687	0.707	0.847	0.867	55.0
3/4	0.750	0.770	0.934	0.954	69.0
13/16	0.812	0.832	0.996	1.016	75.0
7/8	0.875	0.895	1.079	1.099	87.5
15/16	0.937	0.957	1.141	1.161	90.0
1	1.000	1.020	1.204	1.224	92.5

Notes and Reviews

AIRCRAFT

These items, which are prepared by the Research Department, give brief descriptions of technical books and articles on automotive subjects. As a rule, no attempt is made to give an exhaustive review, the purpose being to indicate what of special interest to the automotive industry has been published.

The letters and numbers in brackets following the titles classify the articles into the following divisions and subdivisions: *Divisions*—A, Aircraft; B, Body; C, Chassis Parts; D, Education; E, Engines; F, Highways; G, Material; H, Miscellaneous; I, Motorboat; J, Motorcoach; K, Motor-Truck; L, Passenger Car; M, Tractor. *Subdivisions*—1, Design and Research; 2, Maintenance and Service; 3. Miscellaneous; 4, Operation; 5, Production; 6, Sales.

The Vertical Wind-Tunnel of the National Advisory Committee for Aeronautics. By Carl J. Wenzinger and Thomas A. Harris. Report No. 387. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931. 10 pp., illustrated. [A-1]

The vertical open-throat wind-tunnel of the National Advisory Committee for Aeronautics is described in this report. The tunnel was built mainly for studying the spinning characteristics of airplane models, but may be used as well for the usual types of wind-tunnel tests. A special spinning balance is being developed to measure the forces and moments with the model simulating the actual spin of an airplane.

Satisfactory air-flow has been attained with a velocity that is uniform over the jet to within $\pm$ 0.5 per cent. The turbulence present in the tunnel has been compared with that of several other tunnels by means of the results of sphere-drag tests and was found to average well with the values of those tunnels. Included also in the report are comparisons of results of stable autorotation and of rolling-moment tests obtained both in the vertical tunnel and in the old horizontal 5-ft. atmospheric tunnel.

Investigation of the Diaphragm-Type Pressure-Cell. By Theodore Theodorsen. Report No. 388. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 18 pp., with tables and charts. [A-1]

This report relates to various improvements in the process of manufacture of the N.A.C.A. standard pressure-cell. Like most pressure-recording devices employing thin diaphragms, they would in general show considerable change in calibration with temperature and also some change in calibration with time or aging effect. Some instruments exhibited considerable internal friction.

The Effect of Small Angles of Yaw and Pitch on the Characteristics of Airplane Propellers. By High B. Freeman. Report No. 389. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 11 pp., illustrated. [A-1]

The subject tests were carried out in the 20-ft. wind-tunnel of the National Advisory Committee for Aeronautics to determine the effect on the characteristics of a propeller of inclining the propeller axis at small angles to the relative wind. Tests were made of a full-scale propeller and fuselage combination at four angles of yaw (0, +5, +10 and +15 deg.), and of a model propeller, nacelle, and wing combination at five angles of pitch (−5, 0, +5, +10 and +15 deg.).

The results of the full-scale tests of a propeller and fuselage, without a wing, show that the effect on the propeller performance is small. Similar results are shown by the model test data except that where the propeller is directly in front of the wing there is an appreciable decrease in effective thrust and propulsive efficiency with increase of angle of pitch.

The Aerodynamic Characteristics of Eight Very Thick Airfoils from Tests in the Variable-Density Wind-Tunnel. By Eastman N. Jacobs. Report No. 391. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 14 pp., with tables and charts. [A-1]

A group of eight very thick airfoils having sections of the same thickness as those used near the roots of tapered airfoils were tested in the variable-density wind-tunnel of the National Advisory Committee for Aeronautics. The tests were made to study certain discontinuities in the characteristic curves that have been obtained from previous tests of these airfoils and to compare the characteristics of the different sections at values of the Reynolds number comparable with those attained in flight. The discontinuities were found to disappear as the Reynolds number was increased. The results obtained from the large-scale tests in this series indicate that the N.A.C.A. 0021 airfoil, a symmetrical airfoil having a thickness ratio of 21 per cent, has the best general characteristics.

Metal-Truss Wing-Spars. By Andrew E. Swickard. Technical Note No. 383. Published by the National Advisory Committee for Aeronautics, City of Washington, July, 1931; 31 pp., 9 figs. [A-1]

Since metal-truss wing-spars are coming into general use in the airplane industry, it is necessary that national methods for their design be developed.

The purpose of the study recorded in this thesis was to develop improvements in the current methods for the calculation of the loads in the members of metal-truss wing-spars which are subjected to combined bending and compression.

The material of this thesis is divided into three parts. The derivations of the theoretical concepts are given first. The practical applications of the theory follow. Finally, in the form of an appendix, the effective moment of inertia of an actual metal-truss wing-spar is calculated.

Tests of Six Symmetrical Airfoils in the Variable-Density Wind-Tunnel. By Eastman N. Jacobs. Technical Note No. 385. Published by the National Advisory Committee for Aeronautics, City of Washington, July, 1931; 18 pp., 9 figs. [A-1]

This paper is the first of a series covering an investigation of a family of airfoils all formed from a basic profile. It gives in preliminary form the results obtained from tests in the N.A.C.A. variable-density wind-tunnel of six symmetrical airfoils, differing only in maximum thickness. The maximum-thickness-to-chord ratios are 0.06, 0.09, 0.12, 0.15, 0.18 and 0.21. The results are analyzed with a view to indicating the variation of the aerodynamic characteristics with profile thickness.

Variable-Lift Wings. By F. Duncanson. Published in *The Aircraft Engineer*, supplement to *Flight*, June 19, 1931, p. 41. [A-1]

In this issue Mr. Duncanson takes up the subject of variable-camber wings and comes to the conclusion that, with modern efficient aircraft, the advantages to be derived from the use of variable camber are greater than they were in the older type of machine. He estimates the weights and performances of two types of machine designed to do the same work, one with fixed wings and one with variable-camber

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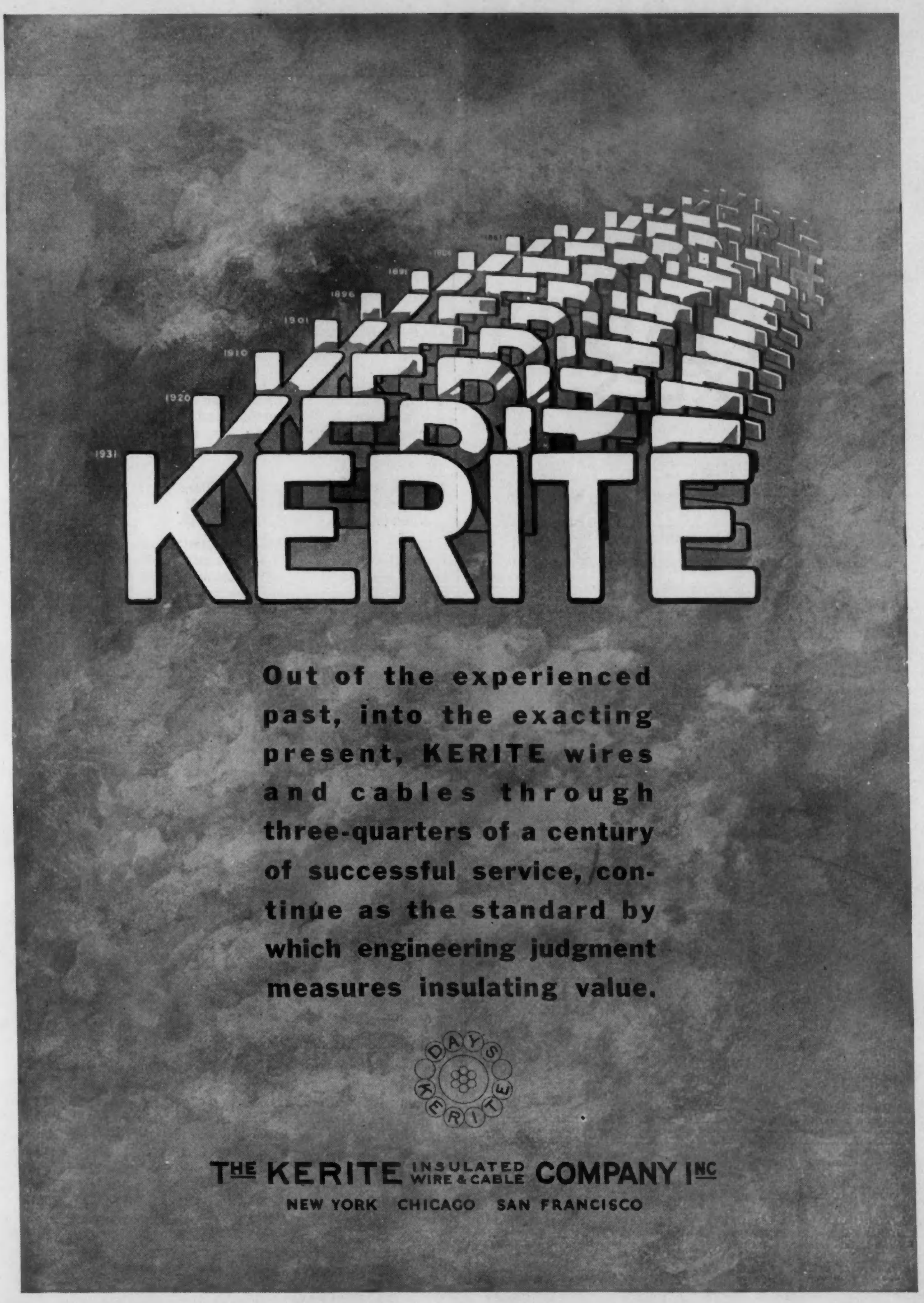

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Notes and Reviews

Continued

wings, and arrives at the conclusions that the variable-camber-wing machine will have a top speed some 12 m.p.h. greater than that of the fixed-wing machine, the rate of climb is very materially better, as are also service ceiling and absolute ceiling. In addition, Mr. Duncanson points out, the use of variable-camber wings enables smaller over-all dimensions to be attained, which in turn means improved maneuverability, better view, and a reduction in fuel consumption. The author does not regard variable-camber gear as a means to reducing landing speed but as a means to better performance and greater maneuverability, and it is from this new point of view that he examines the subject.

On Solid Rivets. By M. Langley. Published in *The Aircraft Engineer*, supplement to *Flight*, May 29, 1931, p. 35. [A-1]

The author sets forth the factors to be considered in determining upon the proper size and strength of rivets for use in aircraft construction and discusses the design of joints, the spacing of the rivets, and the precautions to be observed in workshop practice.

L'Hélice Roue-Libre Paulhan Pillard pour Amélioration du Vol avec Moteur Arrêté. By M. Pillard. Published in *L'Aéronautique*, July, 1931, p. 245. [A-1]

The author, having observed that an airplane engine on which the ignition had been cut still continued to turn over at the rate of 750 r.p.m. because of the air force on the propeller, conceived the idea of developing a free-wheel propeller. Free from the braking action of the engine, the propeller would then make available for useful work the horsepower usually expended in turning over the stalled powerplant.

A theoretical study is made of the free-wheel propeller, comparing it with the adjustable-pitch and conventional keyed type. The development of a practical device is traced through three stages, the final design incorporating a clutch by which the free-wheeling feature is brought into operation or discontinued at will. The free-wheel device is available in three forms, suitable for wood, aluminum and steel propellers.

Tests were made of the free-wheel propeller on both a military and a commercial airplane, and a series of barograms portraying the results of these tests are reproduced. An analysis of the barograms is made to show the gain either of weight or ceiling made possible by the free-wheel device. This unconventional type of propeller is said to be free from vibrations and to make no change in the operation of the airplane except to give a feeling of additional acceleration.

The gains due to the free-wheel device are said to be the same whether used with a small high-speed propeller or a large low-speed propeller. If the weight saving is translated into additional fuel load, it is said to be sufficient to add 4 hr. to the flight range of a bimotor and 2 hr. to that of a trimotor airplane; or it will permit 60 per cent increase in the payload of a bimotor and 40 per cent in that of a trimotor.

Über die Schwingungserscheinungen an Luftschrauben. By Friedrich Seewald. Published in *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, June 29, 1931, p. 369. [A-1]

The author, in this article, surveys the present state of knowledge with regard to vibration in aircraft propellers. He divides the vibrations into two classes: those arising in the propeller itself and forced vibrations imposed from some outside source.

He gives a theoretical treatment of combined torsional

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and deflection vibrations, vibrations with only one degree of freedom at large angles of attack, and the effect of camber in propeller blades. Three sources are assigned for forced vibrations: the uneven running of the engine, the fluctuations in air currents and the lack of symmetry in the airflow patterns in the plane of the propeller. A description is given of an apparatus for the observation of propeller vibration, which was developed for the purpose of checking the theoretical treatment by the results of experiments. The resonance between deflection and forced vibrations and between torsional and forced vibrations is also dealt with.

The author concludes that, with further progress in aircraft design, the problem of propeller flutter will become even more complicated and recommends that individual study be made of each case in the attempt to determine its specific cause.

Flying Dutchman. The Life of Anthony Fokker. By Anthony H. G. Fokker and Bruce Gould. Published by Henry Holt & Co., New York City, 1931; 282 pp., illustrated. Price, $3.00. [A-3]

The autobiography of a man whose life has been one constant romance of action, intrigue, creative achievement and triumph provides enjoyable reading and inspiration for anyone interested in the history of aviation and the men who are responsible for its development.

Wings of Tomorrow. The Story of the Autogiro. By Juan de la Cierva and Don Rose. Published by Brewer, Warren & Putnam, New York City, 1931; 300 pp., illustrated. Price, $2.50. [A-3]

The story of the development of the Autogiro from the earliest experiments up to the perfected flying-machine, as told by its inventor, is of particular interest as it comes at a time when the commercial use of the Autogiro is attracting widespread attention.

What the Autogiro can do and how it does it are discussed with accuracy and authority, but in comprehensible terms. A technical supplement is included for the engineer; a manual of instructions for the pilot.

This story of the Autogiro is indeed a romance of the machine age told by the man who knows it from the beginning, the man who invented it, first built it and first made it fly.

An Investigation of Pressures and Vacua Produced on Structures by Wind. By Harold Mactavish Sylvester. Engineering and Science Series No. 31. Published by the Rensselaer Polytechnic Institute, 1931; 53 pp., illustrated. [A-3]

The belief that many structures, including airship hangars, have been built upon designs involving erroneous wind-pressure assumptions led to the investigation described in this report. The determination of the magnitude and distribution of wind pressures on a type of airship hangar was the purpose of the experiments.

From a study of the results of this and various other investigations, the author concludes that the true distribution of wind pressures on structures is practically beyond the reach of theoretical analysis.

None of the effects of wind seem to be reducible to simple formulas, he states, except the effect of the actual velocity head, and even this can be stated in mathematical terms only in magnitude and not in distribution.

The Meteorological Aspects of Gliding and Soaring Flight. By F. Entwistle. Published in *The Journal of The Royal Aeronautical Society*, June, 1931, p. 423. [A-3]

The author points out that, in so far as the subject of wind structure is concerned, attention has been concen-

(*Continued on next left-hand page*)

Notes and Reviews

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trated mainly on the accumulation and interpretation of data regarding the average direction and speed of the wind currents at different levels, whereas the horizontal variations of wind and the vertical currents which disturb the regular flow of air have received, in comparison, little consideration. The latter aspect is of paramount importance in connection with soaring flight as well as to the stability of aircraft.

This paper, based on 15 years of study of meteorology in relation to aviation, gives pertinent data on this subject.

I. L. I. S. The Stockholm International Aero Show. May 15-31, 1931. Published in *Flight*, May 22, 1931, p. 447. [A-3]

This article gives a brief outline of what was to be seen at the Stockholm Aero Show and is followed in the May 29 issue of *Flight* by a more detailed description of the exhibits, notably the Heinkel amphibian.

The Royal Air Rorce. By F. A. de V. Robertson. Published in *Flight*, June 26, 1931, p. 581; 17 pp., illustrated. [A-3]

Major Robertson gives a brief outline of the growth of the British Air Power from the Balloon Company of the Royal Engineers to the present Royal Air Force over the period from 1890 to 1931.

Fire Prevention on Aircraft. By Fritz Kühn. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Vol. 22, Nos. 7 and 8, April 14 and 28, 1931; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 628; 23 pp., 27 figs. [A-4]

The Dangerous Flat Spin and the Factors Affecting It. By Richard Fuchs and Wilhelm Schmidt. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Vol. 21, Nos. 13 and 14, July 14 and 28, 1930; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 629; 39 pp., 26 figs. [A-4]

The Steady Spin. By Richard Fuchs and Wilhelm Schmidt. Translated from *Luftfahrtforschung*, Vol. III, No. 1, February 27, 1929; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 630; 27 pp. 37 figs. [A-4]

The foregoing three Technical Memoranda were issued during July, 1931, by the National Advisory Committee for Aeronautics, City of Washington.

The Cause and Prevention of Heat Cracks in Aircraft Welding. By H. S. George. Published in *Mechanical Engineering*, June, 1931, p. 433. [A-5]

As a result of a study of localized stresses, the author concludes that the prevention of heat cracks is not difficult at the most, and the necessary procedure is greatly simplified by the fact that practically all cracks fall into two main groups: The edge crack, which predominates, and the crack caused by some internally stressed condition of the metal. A simple expedient suffices to prevent each type of crack; for the edge crack, welding toward the edge; and for the other type, a preliminary heating to remove latent stresses. Auxiliary expedients and precautions for application to individual cases are also considered.

BODY

Motor Body Designing Problems. By George J. Mercer assisted by Robert P. Williams. Published by Ware Bros. Co., Philadelphia, Pa., 1931; 131 pp. of text, 61 drawings. Limited edition. [B-1]

This volume consists of 61 drawings accompanied by a separate manual of instructions and explanations.

The author states that the book has been compiled to

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Continued

aid what in carriage days was called the "improver," that class of young men who have passed all the initial stages in learning the craft but lack that final finish which comes from general experience. Therefore, all preliminary work that is required for the beginner in the study of drafting has been omitted. The book is intended to supply the lack of knowledge that retards the young draftsman and is a reference for the mature draftsman.

Mr. Mercer is well known for his many contributions on the subject of body design to automotive journals.

EDUCATION

Teaching Engineering and Business Students to Deal with Men and Manage Industrial Relations. Published by the Society for the Promotion of Engineering Education, New York City, 1931; 40 pp. [D-3]

This pamphlet constitutes a report of a conference held on March 28, 1931, at the home of Sam A. Lewisohn in cooperation with the Society for the Promotion of Engineering Education. Plans were made to hold another conference next year.

ENGINES

The Effect of Injection-Valve-Opening Pressure on Spray-Tip Penetration. By A. M. Rothrock and E. T. Marsh. Technical Note No. 384. Published by the National Advisory Committee for Aeronautics, City of Washington, July, 1931; 4 pp., 3 figs. [E-1]

The effect of various injection-valve-opening pressures on the spray-tip penetration was determined for several injection pressures. A common-rail fuel-injection system was used. For a given injection pressure, a maximum rate of penetration was obtained with an injection-valve-opening pressure equal to the injection pressure. As the excess of the injection pressure over the injection-valve-opening pressure was increased for a given injection pressure, the effect of the injection-valve-opening pressure on the spray-tip penetration was increased.

Rapid Calculation of Bearing Loads Can Be Made with Simplified Forms. By Robert N. Janeway. Published in *Automotive Industries*, May 30, 1931, p. 831 and June 6, p. 875. [E-1]

Bearing life has once more become a serious problem with the advent of the present high-pressure tendency in engine design, which has brought about operating speeds of 4000 r.p.m. as not unconventional practice, especially in eight-cylinder powerplants.

The author presents in this article a time-saving method for determining pressures by the use of simple arithmetic processes with the charts shown in the article.

Fuel Tests in Low and High-Speed Engines. By L. J. LeMesurier and R. Stansfield. Published in *The British Motorship*, June, 1931, p. 116. [E-1]

The research described includes an attempt to cover certain aspects in the behavior of a series of typical fuels in both slow and high-speed Diesel engines. As far as possible it was directed toward problems presented directly by engine users and also toward more fundamental aspects of combustion which, it is believed, need to be more generally understood before the mechanism necessary for combustion, particularly at high speeds, can be perfected.

Fourteen different fuels were examined and tested on four engines; the tests were conducted in the research laboratory of the Anglo-Persian Oil Co.

In conclusion the authors state that it is safe to prophesy that the rating of heavy oils for Diesel engines, as for gasoline engines, must include suitable engine tests.

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Influence du Piston dans la Consommation d'Huile. By M. Dintilhac. Published in *Journal de la Société des Ingénieurs de l'Automobile*, May, 1931, p. 1395. [E-1]

The author's thesis is that the quantity of oil consumed by an engine is influenced far more by the design of the piston, specifically the character and location of the oil-return groove, and the speed of the engine than by the type of oil used. His proof consists of a theoretical exposition of piston-rings, clearances and oil-grooves and a series of charts showing the results of oil-consumption tests with various pistons, both cast iron and aluminum, and oils of different types.

Versuche an einem Niedrig Verdichtenden Fahrzeugmotor bei Kompressorloser Brennstoffeinspritzung und Fremdzündung. By Professor Düll. Published in *Automobiltechnische Zeitschrift*, May 10, 1931, p. 399. [E-1]

Research on the possibilities of a low-compression heavy-oil engine with direct fuel injection and spark ignition has been in progress in the laboratory of the Braunschweig technical university since 1927. The principles investigated are those incorporated in the Hesselmann engine, described in recent technical literature.

A converted Dorner Diesel engine, in which the compression ratio was lowered from 13.4 to 5.6 and 7.93 to 1 and spark ignition and means for creating turbulence were provided, was used in the investigation. The research was directed toward determining the most favorable injection and spark angle, the specific fuel consumption at compression ratios of 5.6 and 7.93:1, the influencee of injection angle at full and partial load, and the relation betwen spark timing, combustion velocity, efficiency and speed for three different fuels.

The results are said to indicate that the type of engine in question has a promising future.

Beurteilung von Kurbelwellenbrüchen. By E. A. Wedemeyer. Published in *Automobiltechnische Zeitschrift*, July 20-31, 1931, p. 472. [E-1]

Emphasis is laid on the importance of the consequences of crankshaft breakage and the multiplicity of causes that may be assigned for such occurrences. The author then cites a number of specific instances, describing and illustrating the breaks, analyzes the basic reasons and suggests methods of prevention of similar ruptures.

The first instance is that of a crankshaft of a two-cylinder engine, in which the break occurred in a cheek near to the crankpin. The cause is traced to a bending stress due to piston forces. Two cases are given of breaks in the rear ends of four-cylinder-engine crankshafts, both due to bending stress, traced in the first instance to a faulty main bearing and in the second to the manner of the flywheel coupling. Cases of breakage in the cheek adjacent to the middle bearing of four-cylinder-engine crankshafts are frequent, the author says, and are too often and without justification laid to the door of faulty material. The cause is rather to be sought in the heavy loading and faulty lubrication of this section of four-throw crankshafts, which lead to their deformation in operation. An illustration is given of a break due to a hair-crack in the metal, and two instances in which torsional vibration was the damaging factor are cited and analyzed.

Principles and Problems of Aircraft Engines. By Minor M. Farleigh. Published by John Wiley & Sons, Inc., New York City and London, 1931; 277 pp., illustrated. Price, $3. [E-2]

The writer presents material on the servicing of aircraft engines in non-technical form to assist the reader in pur-

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suing intelligently the important ground-work involved in the maintenance of engines.

A considerable background of fundamental principles of design and operation is given in the first chapters, followed by more detailed instructions on valve timing, firing order, ignition timing, magnetos, carburetion, superchargers, lubrication and trouble shooting, with special chapters on the Pratt & Whitney Hornet engine, the Kinner K-5 engine, and the Packard Diesel engine. An index and glossary of aircraft-engine terms are included.

MATERIAL

Methanol Antifreeze and Methanol Poisoning. By W. P. Yant, H. H. Schrenk and R. R. Sayers. Published in *Industrial and Engineering Chemistry*, May 1931, p. 551. [G-1]

With the advent of synthetic processes for making methanol from stack gases, water gas, and coal gas, it is now available in large quantities for use as a radiator antifreeze.

Owing to the existence of many conflicting and confusing data on the poisonous effect of methanol, an investigation was desirable as to its toxicity, not only with reference to its particular use as an antifreeze but from a consideration of fundamental information that could be used in evaluating the dangers from manufacturing and handling this product. The United States Bureau of Mines was requested to make the investigation and entered into a formal agreement with the Carbide & Carbon Chemicals Corp., the Du Pont Ammonia Co. and the Commercial Solvents Corp. to carry out the investigation cooperatively.

This report herein reviewed was prepared mainly to acquaint persons interested in this type of investigation with the plan, procedure and test equipment that is being used.

Such conclusions are drawn as the data collected thus far warrants, and the information obtained to date indicates that no hazard to health is involved in the reasonable use of methanol for antifreeze purposes.

The Surface Decarburization of Steel at Heat-Treating Temperatures. By W. E. Jominy. Engineering Research Bulletin, No. 18. Published by the Department of Engineering Research, University of Michigan, Ann Arbor, Mich., March, 1931; 51 pp. [G-1]

The surface decarburization of steel at heat-treating temperatures is influenced by a large number of factors, of which the more important are furnace atmospheres, pressures, temperatures, periods of exposure, and scale on the steel. To make any predictions regarding the decarburizing action, the effect of the individual gases that may be present in the furnace atmospheres must be considered in relation to one another. It is often possible to use sufficiently short periods of exposure to minimize the decarburizing effects. These effects obtain in most steels, although steels of certain compositions may decarburize more rapidly than others.

The Effect of Various Annealing Temperatures on Cold-Worked Low-Carbon Steel. Engineering Experiment Station Bulletin No. 35. By H. E. Publow, C. M. Heath and R. A. Gezelius. Published by the Michigan State College of Agriculture and Applied Science, East Lansing, Mich., March, 1931; 17 pp., illustrated. [G-1]

In this bulletin the authors discuss the results of experiments to determine the best temperatures for annealing cold-worked low-carbon steel. In general, the best annealing temperatures were found to lie just below the lower critical point. Steel annealed above the critical range,

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unless cooled very slowly, is not in as perfectly annealed condition as one annealed at 1250 deg. fahr. There appeared to be no difference in microstructure. Annealing temperatures below 1000 deg. fahr. were not found satisfactory.

Report of Committee D-2 on Petroleum Products and Lubricants, the American Society for Testing Materials. Preprint of report presented at the A.S.T.M. Annual Meeting in Chicago, June 22 to 26, 1931. [G-1]

In addition to the reports of the various technical committees which come within the jurisdiction of Committee D-2, this preprint includes the proposed revised tentative method of test for vapor pressure of natural gasoline (Reid method). Criticisms of this tentative method are solicited.

Relative Quality of Lubricants Shown by Navy Bearing Test. By J. M. Evans. Published in *National Petroleum News*, June 10, 1931, p. 47. [G-1]

Two articles previously published by *National Petroleum News*, Evaluating of Lubricating Oils by the Work Factor Method, by O'Neil and McGeary, and Relative Resistance of Lubricating Oils to Decomposition in Use, by Lederer and Zublin, were reviewed in this column for October, 1930. The article by Lederer and Zublin gave results obtained by them in studying lubricating oils by the Navy method, particularly as to the difference shown between oils of paraffinic and of naphthenic origin, and the relative importance of the various factors used in the Navy test in estimating lubricant values.

The present article reports results obtained by the author and his organization in testing lubricating oils by the Navy method, with special attention to the difference in "work factor" results obtained from oils of identical origin but of different degrees of refinement. He found that much of the difference claimed to exist between oils manufactured from different bases is due to failure properly to refine naphthenic oils, and that the latter, when properly refined by modern methods, show results decidedly different from those previously reported by some investigators.

Viscosity-Temperature Relationships of Lubricating Oils. By R. G. Sloane and Carl Winning. Published in *Industrial and Engineering Chemistry*, June, 1931, p. 673. [G-1]

It is standard practice in this country to determine viscosities of lubricating oils at temperatures of 100, 130, and 210 deg. fahr. (37.8, 54.4, and 98.9 deg. cent.). However, the viscosity at some other temperature is often required. Pumping effort and fluid-film friction are functions of the viscosity at the temperature in question, and this temperature may be such as to make viscosity determination inconvenient or impossible with the usual Saybolt viscosimeter. In such cases it is very helpful to be able to obtain the viscosities mathematically or graphically by extrapolation from known values.

Most of the graphical methods devised comprise plotting viscosity versus temperature on such a system of coordinates that a straight line is obtained. Since no mathematical expression has yet been given to these coordinate systems, they are not easily reproduced and a market has consequently developed for such ready printed forms as those of MacCoull and Herschel, which permit the desired linear plotting. Naturally, the forms have not always covered the desired range and they have on occasion been extended, as by Larson.

Extrapolation on such charts over wide temperature ranges based on viscosities at 100 and 210 deg. fahr. (37.8 and 98.9 deg. cent.) may give viscosity data greatly in error, and figures so obtained can be considered approximations of only a low order.

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AMERICAN BOSCH COIL

DEPENDABLE HIGH TENSION IGNITION

DEPENDABLE HIGH TENSION IGNITION

THE newest series of American Bosch Dependable High Tension Ignition Coils consist of—a Standard 6 volt coil—a Universal 6 volt coil—a Multi-speed 6 volt coil—and a Multi-speed 12 volt coil. This new series of coils is adaptable to and quickly mounted upon all types and sizes of internal combustion engines designed for battery ignition. These new electrical units of the American Bosch are of advanced and revolutionary design. They are rugged, absolutely dirt proof, waterproof and oil proof, and they are always dependable and efficient.

BOSCH
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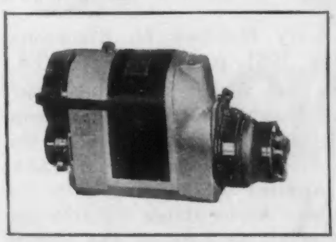
Super-Energy
MAGNETO



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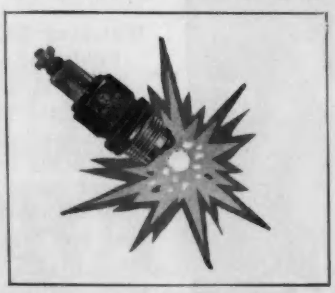
ROBERT BOSCH, A. G

Pyro-Action
SPARK PLUGS



AMERICAN BOSCH
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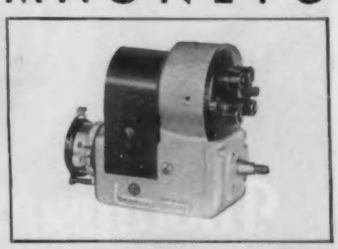

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Continued

The authors describe an attempt to find a simple mathematical expression by which a linear plot can be obtained and point out that if such a relation can be found it will free the worker from printed forms, which are often either not available or not adapted to the particular problem.

On the Yield-Point of Mild Steel. By Fujio Nakanishi. Report No. 72 of the Aeronautical Research Institute, Tokyo Imperial University, June, 1931; 140 pp., illustrated. [G-1]

Various theories concerning the elastic limit have been advanced, but none of them can account for the yielding of mild steel. The object of this paper is to propose a new theory. The author considers that the yielding of material is a problem of stability, analogous to the critical point of viscous flow through a pipe. The material will yield when the state of stress becomes unstable; all the stress distribution in the body must therefore have effect on the yield-point.

Fatigue Tests in Shear of Three Non-Ferrous Metals. By H. F. Moore and R. E. Lewis. Preprint of paper presented at the Annual Meeting of the American Society for Testing Materials, Chicago, June 22 to 26, 1931. [G-1]

The results of a limited number of tests on copper, brass and duralumin are reported, giving data on the fatigue strength in shear for these non-ferrous metals. The testing machines and test-specimens used are described. Fatigue tests were made in reversed flexure, reversd torsion, and with cycles of torsion varying from zero to the maximum.

The endurance limit in reversed torsion bears a higher ratio to the endurance limit in reversed flexure than is the case for ferrous metals.

Symposium on Effect of Temperature on the Properties of Metals. Preprints of the papers presented at a joint meeting of the American Society of Mechanical Engineers and the American Society for Testing Materials held in Chicago, June 23, 1931; 620 pp. [G-1]

This collection of papers represents the result of an effort to take stock of present knowledge and appraise recent accomplishments in the application of metals at high and low temperatures and constitutes a valuable contribution in this field.

Of particular interest to the automotive industry is the paper, Engineering Requirements in the Automotive Industry for Metals Operating at High Temperatures, by A. L. Boegehold and J. B. Johnson, which includes a consideration of metals for use in pistons, valves, cylinders and bearings, with special reference to Diesel engines and aircraft engines.

A bibliography prepared by Lois F. McCombs, supplementary to the one published with the 1924 Symposium, is included.

Watching Stresses at Work. By Hendley N. Blackmon. Published in *Machinery*, June, 1931, p. 737. [G-1]

Mr. Blackmon discusses the use of the "photo-elastic" apparatus, which shows, by different colors on a screen, the magnitude and location of stresses in models of the parts being investigated. The models are made from transparent materials. Loads are applied to the models in the same manner as in actual service. Since stress distribution does not depend upon the material, as long as the elastic limit is not exceeded, results obtained with the models apply directly to steel and other materials.

This photo-elastic apparatus thus provides a practical method of studying stresses in both simple and complicated parts, either stationary or moving, and it is hoped will solve the difficulty in determining the strength of machine

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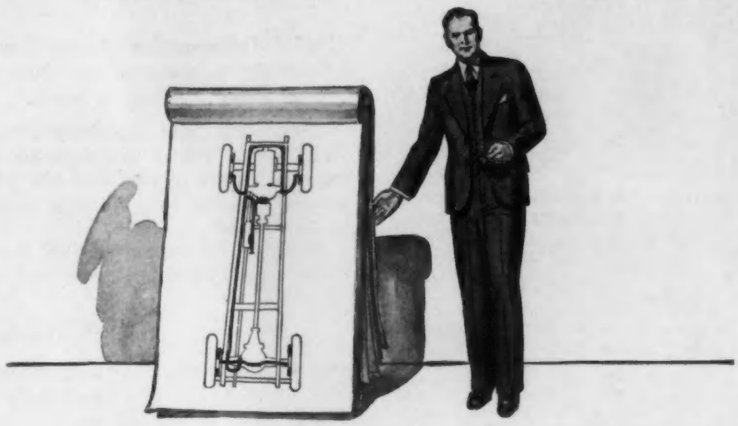

Notes and Reviews

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members or other structures that are of such design that a satisfactory calculation cannot be made by the use of mathematical formulas.

Useful Information About Lead. Published by the Lead Industries Association, New York City, 1931; 104 pp., illustrated. Price, 50 cents. **[G-3]**

This book tells concisely the story of lead and its principal uses. Short chapters are devoted to the major industries consuming lead and the part that lead plays in them as well as to the history, mining, smelting and refining of the metal.

A table of properties of lead, which is included, gives mechanical, thermal, electrical, optical and other constants.

MISCELLANEOUS

The National Physical Laboratory Report for the Year 1930. Published by His Majesty's Stationery Office, London. England, 1931; 295 pp. **[H-1]**

This volume covers the year's progress in research on a wide variety of projects at the National Physical Laboratory. Many of the investigations are of particular interest to the automotive engineer, notably those under the direction of the Aerodynamics, Metallurgy, and Engineering Departments.

X-Ray Inspection of Welds. By Herbert R. Isenburger. Published in the *Journal of the American Welding Society*, May, 1931, p. 17. **[H-5]**

The author points out that it is often desirable to have a nondestructive test which will prove the soundness of a weld and at the same time give the assurance that the material will stand the required strain of service. The X-ray is a sure and reliable means of answering the salient questions about welds, Mr. Isenburger contends. He describes briefly the equipment required and results obtained by using different methods of X-ray test.

MOTORCOACH

Bus Operations of Electric Railways in 1930. A.E.R.A. Bulletin No. 358. Published by the American Electric Railway Association, New York City, 1931; 115 pp. **[J-4]**

This bulletin contains a complete tabulation of all the replies received by the American Electric Railway Association, to a questionnaire entitled, Bus Operations, sent out to all electric railways having motorcoach operations. The questionnaire called for detailed information relating to the revenues, expenses and operating statistics of the bus operations of electric railways for the calendar year 1930, compared with 1929.

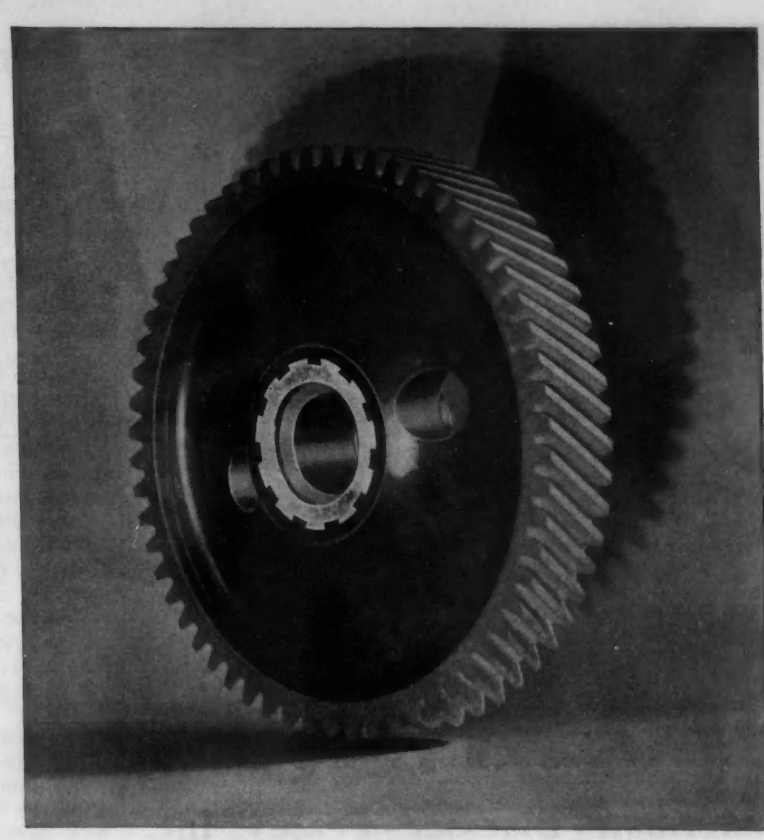
Replies were received from 194 bus undertakings, including 120 city companies, 28 interurban companies, and 46 combination city and interurban companies.

Bulletin No. 357 gives a complete statistical analysis of the operations of electric railways in 1930 compared with 1929.

MOTOR-TRUCK

An Analysis of Goods-Vehicle Performance. Published in *The Commercial Motor*, May 12, 1931, p. 422. **[K-5]**

A summary of information obtained from a series of comprehensive road tests on a group of commercial vehicles representative of the various classes of chassis is presented in this article with the aid of graphs. Acceleration from rest, average fuel-consumption rates; average gross weights of vehicles of different payload capacities, and stopping distances of the various classes of vehicle are among the factors studied.



Personal Notes of the Members

(*Concluded from p. 251*)

served as assistant chief engineer, **Albert G. Geistert** is at present located at Detroit, his address being 586 Goldengate Ave.

T. W. Hallerberg is now full-size body-layout draftsman with the Pierce-Arrow Motor Car Co., of Buffalo, N. Y. He was formerly assistant chief engineer of the Pickwick Motor Coach Works, of Inglewood, Cal.

E. R. Jacobi, of 3790 Cortland Ave., Detroit, has announced that he will rest for one year in order to regain his health. His former position was that of executive engineer for the Kelsey-Hayes Wheel Corp., of Detroit.

William F. Jennings, president and treasurer of the Bound Brook Oil-less Bearing Co., was elected president of a subsidiary company recently organized under the name of the Fischer Foundry Corp., of Bound Brook, N. J., to manufacture a full line of bronze and aluminum castings. The new company will occupy the foundry building formerly used by the bearing company in Middlesex Borough.

George H. Kublin has been advanced from the position of assistant chief engineer of the Auburn Automobile Co., of Auburn, Ind., to that of chief engineer. He has been associated with the Auburn company for the last three years.

Ernst von Mertens has become assistant superintendent of the Apollo Magneto Co., of Kingston, N. Y.

William B. Oakley, formerly automotive service engineer with the General Motors Export Co., of New York City, is now service manager of the North Essex Buick Co., of Montclair, N. J.

Harold L. Pope has accepted the position of assistant to the president of the Northwestern Leather Co., of Sault Ste. Marie, Mich.

José Rosan is now employed by the American Airplane & Engine Corp., of Farmingdale, Long Island, N. Y. His previous connection was with the Lycoming Mfg. Co., of Williamsport, Pa., as engine designer.

Walter C. Robbins, having given up his executive position as vice-president of the Gabriel Co., of Cleveland, in charge of engineering and manufacturing, is now vice-president and general manager of the Thermo Hydraulic Shock Absorber Co., of Cambridge, Mass.

Charles E. Sargent has been appointed consulting engineer of the National Transit, Pump & Machinery Co., of Oil City, Pa. His previous post was in the consulting engineering department of the Westinghouse Electric & Mfg. Co., of East Pittsburgh, Pa.

William H. Welch has transferred his connection from the Moto Meter Gauge & Equipment Corp., of Toledo, Ohio, for which he was research engineer, to the Firestone Tire & Rubber Co., of Akron, Ohio, for which he is chief spark-plug engineer.

Capt. Ennis C. Whitehead, of the Air Corps of the Army, has been appointed commanding officer of the 36th Pursuit Squadron stationed at Selfridge Field, Mt. Clemens, Mich. Captain Whitehead was previously maintenance engineer on aircraft and engines in the Materiel Division of the Air Corps at Langley Field, Hampton, Va.

Camillo Wieden is now employed by the Wright Aeronautical Corp., of Paterson, N. J., as an engine checker.

P. S. Williams, who until recently was general factory manager of the Hall-Scott Motor Car Co., of Berkeley, Cal., is now general manager of the Merco Nordstrom Manufacturing Co., of Oakland, Cal., makers of lubricated plug valves for pipe lines.

Arthur L. Wright has joined the Electrolux Co., of Richmond, Va., maker of electric household equipment, in the sales and service branch. Formerly he was a physical metallurgist with the Linde Air Products Co., of Buffalo.

J. G. Zimmerman relinquished his position of research engineer with the Burgess Battery Co., of Madison, Wis., on May 1 and is now engaged in research and development work on some inventions of his own and is also doing some consulting work in electrical lines.